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Flood Plain Management Services
Barrington, Rhode Island

Rhode Island
Sea Level Rise Impact Investigation

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This study reviews the most current technical literature on sea level rise effects and predictions as well as focuses on determining the potential for increased flooding. The study provides an updated hydraulic analysis and an analysis of flooding impacts on land, structures, and the salt marsh for the coastal community of Barrington, Rhode Island.

The study found that impacts due to sea level rise are extremely site specific and regulatory agencies should focus on the sea level rise effects associated with historic sea level increases when evaluating future management strategies, while continuing to monitor sea level trends.

This sea level rise impact investigation was accomplished by the New England Division, U.S. Army Corps of Engineers, Planning Directorate, Long Range Planning Branch (LRPB) for the State of Rhode Island.

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EXECUTIVE SUMMARY

This sea level rise impact investigation was accomplished by the New England Division, U.S. Army Corps of Engineers, Planning Directorate, Long Range Planning Branch (LRPB) for the State of Rhode Island. The study was funded under the authority provided by the Corps of Engineers' Section 206 Flood Plain Management Services (FPMS) program. The study reviews the most current technical literature on sea level rise effects and predictions as well as focuses on determining the potential for increased flooding. The study provides an updated hydraulic analysis and an analysis of flooding impacts on land areas, structures, and salt marshes in the coastal community of Barrington, Rhode Island.

The study found that since many factors affect sea level rise and because of the diversity of sea level rise predictions, it is crucial to understand the inherent uncertainty involved. To overcome some of this uncertainty, several sea level rise projections were compared over a time frame of 100 years. Generally, predictions were consistent with historic trends for about the first 40 years after which there were some sharp disparities. In addition, the study focused on a range of sea level rise for the updated hydraulic analysis rather than select any one particular model. Sea level rise increments of 1, 2, 3, 6 and 9 feet were selected as increments representative of various sea level rise scenarios. The 1 foot sea level rise condition corresponded to the historic trend. Other more drastic sea level rise projections were highly variable and ranged typically from a few feet to 9 feet and greater.

The study found that as sea level increases, wave height and wave runup will create greater effects contributing to increased risks of coastal flooding. However, this study found that assessing the impacts due to sea level rise is extremely site specific. Barrington, Rhode Island with its diverse mix of coastal features, natural resources, and developmental characteristics provides a good example, for regulatory or planning agencies, of the range of impacts that would potentially occur. The study revealed that sea level rise effects vary considerably

according to such factors as: a) slope; b) coastline and topography; and c) land use, i.e. undeveloped, developed, etc.

The study found that the hydraulics of Barrington is primarily governed by wave height and therefore low, flat terrain areas will tend to experience the highest potential for increased flooding. Most of the areas affected are beach areas, or wetland-designated areas which have very flat slopes. Generally, those areas which are currently within the 100-year coastal flood limits will have the greatest potential for increased flood impacts resulting from sea level rise. The study also discusses the potential effects that sea level rise would have on salt marsh development and groundwater supplies.

Sea level rise will increase flooding impacts and have a corresponding influence on social, political, economic, and environmental concerns. Therefore, to address these concerns and plan for future development , it is first necessary for those local and state governmental agencies responsible for managing the coastal zone, to create a strategy for developing planning policy. This study provides a model to assist in this decision-making process. Effects from both short-term (30-40 years) and long-term (100 years) sea level increases should be considered. However, from a practical standpoint the short-term influence should be given higher priority.

The study suggests that the regulatory functions of the RI DEM and similar organizations focus on sea level rise effects associated with historic sea level increases when evaluating future management strategies, while continuing to monitor sea level trends. The study also recommends that more detailed analyses of the physical effects on coastal erosion, ground water and coastal salt marsh areas be undertaken by those agencies responsible. The study recommends that policy-makers be informed as to the complex effects that may result from sea level rise and have a clear understanding of the coastal processes involved.

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I. Introduction

A. Background

This study is in response to concerns of the State of Rhode Island regarding future effects of increased sea level rise on coastal communities in Rhode Island. The State and the Corps of Engineers considered several coastal communities before selecting the community of Barrington, Rhode Island to study. The reasons for selecting Barrington, Rhode Island are discussed later in this report. This study also involved a review of technical literature on current sea level rise projections. The State of Rhode Island is particularly interested in this sea level investigation in order to facilitate the process of evaluating future state policies for development along the coast. The study will provide assistance to the state in long range planning to ensure that natural resources, public health and safety are properly protected.

B. Authority

This study was initiated by the New England Division, U.S. Army Corps of Engineers, Planning Directorate, Long Range Planning Branch (LRPB) for Rhode Island Narragansett Bay Project. Since beginning this study, the Rhode Island Narragansett Bay Project was disbanded and the study was completed for the Rhode Island Department of Environmental Management (RI DEM) office. The study was funded under the authority provided by the Corps of Engineers' Section 206 Flood Plain Management Service (FPMS) program.

C. Purpose and Scope

The purpose of this investigation is to estimate the future limits of the 100-year coastal flood boundaries for selected areas based on various increments of rise in sea level for the community of Barrington, Rhode Island. The study provides a description of pre-flood conditions in terms of land characteristics and identifies various sea level rise projections, an updated hydraulic analysis, and presents maps illustrating the effects on the 100-year flood limits on specific areas within the community. The report also qualitatively discusses the effects on land, structures and saltwater marsh.

II. Project Study Area

A. Location/Community Selection

Initially, LRPB and the State identified three (3) coastal communities as potential candidates for studying the effects of sea level rise. The suggested communities were: 1) Barrington; 2) North Kingstown; and 3) Warwick. Each community was evaluated based on topographic, land use and environmental characteristics and the availability of necessary data for the analysis.

Barrington was selected as the most appropriate study site because existing data needed for the analysis was more readily available than for the two alternative communities. In addition, LRPB was informed that the Federal Emergency Management Agency (FEMA), Region I had contracted with a private consultant, ENSR Inc., to perform an updated Flood Insurance Study. Since an updated hydraulic analysis was being performed, LRPB determined that using this most recent data would provide the best baseline information for the Corps' study. In addition, Barrington possessed a variety of natural resources as well as developmental characteristics useful for this investigation. The community contained saltwater marsh areas, some coastal dunes and banks, both A and V floodplain zones as well as developed and undeveloped areas. In general, A zones are areas inundated by the 100-year flood. V zones represent coastal high hazard areas inundated by the 100-year flood which have additional velocity hazards associated with waves of 3 feet or greater. Of particular significance was the presence of both flat terrain beaches governed by wave height and steep cliffs controlled predominantly by wave runup.

B. Sea Level Rise Projection

1. Background

The scientific community has recognized concerns over the potential impact that long term sea level rise could have on the coastal environment and the economy. Some authorities have argued the contrary view, asserting that the earth is entering a new ice age and sea level is dropping. However, based on a cursory review of recent literature on this subject, the predominant view suggests that sea level is increasing. Scientific researchers have suggested that increased human activities have lead to elevated atmospheric concentrations of carbon dioxide and other gases. These gases in turn have caused a warming of the earth contributing to the sea level rise over the last century.

Among the consequences of global warming will be higher sea levels and changes in precipitation patterns. Global warming will create more extensive and rapid accumulation or melting of ice and snow in alpine and/or polar regions and actual contraction or expansion of upper ocean waters. These "greenhouse effects" will contribute to increases in "absolute" global sea level. However, because of the dynamic nature of the earth's atmosphere, ocean, global crustal motion and local crustal motion, global sea level rise is not evenly distributed throughout the earth. Because changes in sea level cause a change in vertical elevation of the oceans measured with respect to a known reference point on the land, landward motion will be an important consideration. Consequently, relative or local sea level provides a better indicator for trends in sea level rise for planning purposes. In addition, because the coastal zone is often characterized by low flat terrain, increased elevations of sea level will have a significant impact on horizontal changes in the shoreline.

Consideration of historic trends in sea level rise is often used in hydraulic studies because they provide the best indicator of future trends versus predicted values. For instance, the historic data for New England indicates that sea level elevation is rising. In the National Research Council's (NRC) publication, an examination of some of the recent trends is made. Based on Figure 1-1 from the NRC publication, the best estimate for the sea level rise for Newport, Rhode Island, the closest community to Barrington listed, is about 2.0 millimeters (mm) per year (See Figure 1).

2. Discussion of Various Sea Level Rise Projections

There are a diverse number of projections made by scientific researchers on the magnitude of sea level rise. A popular approach was provided by Hoffman who developed various sea level rise scenarios based on low and high assumptions of all the major uncertainties (Hoffman, 1983). The major factors accounted for include: thermal expansion of ocean waters, melting of mountain glaciers, melting of Greenland glaciers and Antarctic ocean glaciers (NRC, 1987). Estimating the significance of these various processes will require an estimate of global warming. Hoffman's projections illustrate the complexity involved in modeling the future trends of sea level rise. Moreover, because of difficulty in modeling certain factors as well as modeling unknowns, projections have to be revised. Hoffman revised earlier projections to include updated snow and ice melting effects, accounting for glacial process models not present in his previous projections (Hoffman, 1986).

This variability and interrelationship of factors involved in sea level rise make it difficult to predict an accurate level. As illustrated by the Hoffman models, there is a wide range of possibilities for sea level rise depending if one looks at short term effects (over the next 30 to 40 years) or long term effects (over the next 100 years). For example, Hoffman's models at year 2080 show a range of 1.5 to 9.0 feet sea level rise whereas at year 2000 less than 0.5 foot sea level rise is predicted. Hoffman's models also do not consider the effects of local subsidence, a crucial factor when the magnitude of sea level rise is minimal.

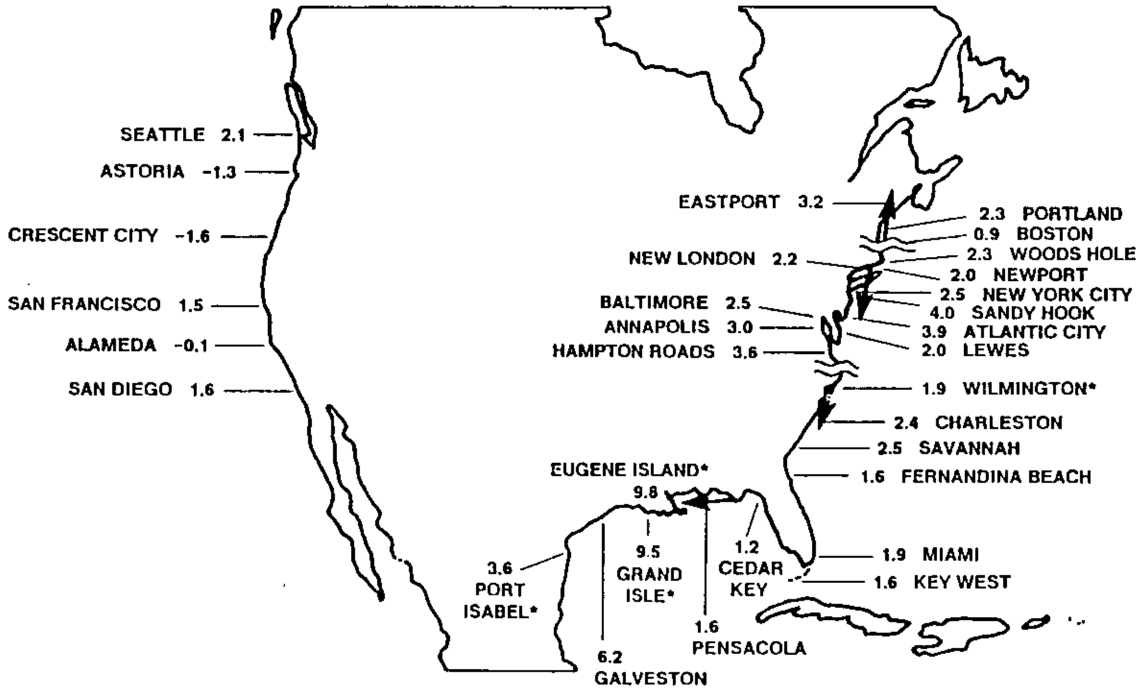


FIGURE 1-1 A summary of the present best estimates of local relative sea level changes along the U.S. continental coastline in mm/yr. The figures are based on the tide gauge records over different intervals of time during the period 1940–1980. Much regional variability is evident. Source: Adapted from Stevenson et al. (1986).

From National Research Council, Marine Board, 1987, "Responding to Changes in Sea Level: Engineering Applications," p. 10, Figure 1-1

FIGURE 1

3. Methodology for Selection of Sea Level Rise Scenario

Because prediction of future sea level rise is such a difficult proposition with many resulting implications, relying on one particular scenario is inappropriate. In addition, the study suggests that greater emphasis should be placed on historic sea level rise trends for long range planning purposes. Corps of Engineers policy indicates that until evidence to demonstrate otherwise is found, the local or regional history trends should take precedence.

Some degree of compromise was necessary in deciding whether to use a purely historic sea level rise or one of the many predictive models. There were two primary criteria that both the New England Division and RI DEM wanted to consider: 1) sea level rise projections that were in the mainstream of other estimates; and 2) historic trends for a given area. All these various scenarios were plotted and analyzed for a time period of 100 years. A duration of 100 years was judged to be a long enough period in which to perform the analysis (See Figure 2). Based on literature research, particularly estimates as found in Table 2-1 and Table 2-2 , page 27 of "Responding to Changes in Sea Level", Hoffman's low and high projections were determined to be appropriate for our analysis. Hoffman's projections provided a broad and representative range for sea level rise. As illustrated by Figure 2, there is much variation in the predictive models. Because of this uncertainty, it was decided not to choose one particular model to follow. Instead, the approach used was to select specific incremental changes in sea level elevations over the study period. Based on Figure 2, sea level rise increments of 1 foot, 2 foot, 3 foot, 6 foot and 9 foot were selected as the increments representative of the various sea level rise scenarios. By selecting these specific elevations, one could easily correlate these levels to the different projection and time periods. For instance, Hoffman's low projection predicts a rise of 2 feet occurring in the year 2090 whereas this same elevation may occur at year 2040 under Hoffman's high projection. Increments less than 1 foot were not used due to the limitations of the available contour mapping and the accuracy of the hydraulic analysis.

III. Hydraulic Analysis
A. General

Based on the factors discussed in the previous section, the hydraulic analysis examines several whole foot incremental changes in sea level. Besides providing a more flexible approach to the comparison of sea level rise projections, it limits the number of computer runs for the hydraulic analysis to a more manageable level of effort.

This study focuses primarily on the increased flooding levels and flood zone limits resulting from rising sea level. Therefore, it was necessary to compare the existing 100-year coastal flood limits to the new limits created by the different sea level rise scenarios. Because this study would provide assistance for long range planning, the current analysis used in developing the National Flood Insurance Program (NFIP) 100-year flood limits was required to establish the initial base condition. Moreover, because changes in the modeling methodology have been made since the Flood Insurance Study was published, the delineations were updated to the current Federal Emergency Management Agency (FEMA) criteria.

Two types of wave processes govern hydraulic analysis of coastal flooding for this investigation. First, a wave height analysis was performed to determine wave heights and corresponding wave crest elevations for areas inundated by tidal flooding. Secondly, a wave runup analysis was performed to determine the height and extent of runup beyond the limit of tidal inundation. The results of these analyses were combined into a wave envelope, which was constructed by extending the maximum wave runup elevation seaward to its intersection with the wave crest profile. The methodology is described in

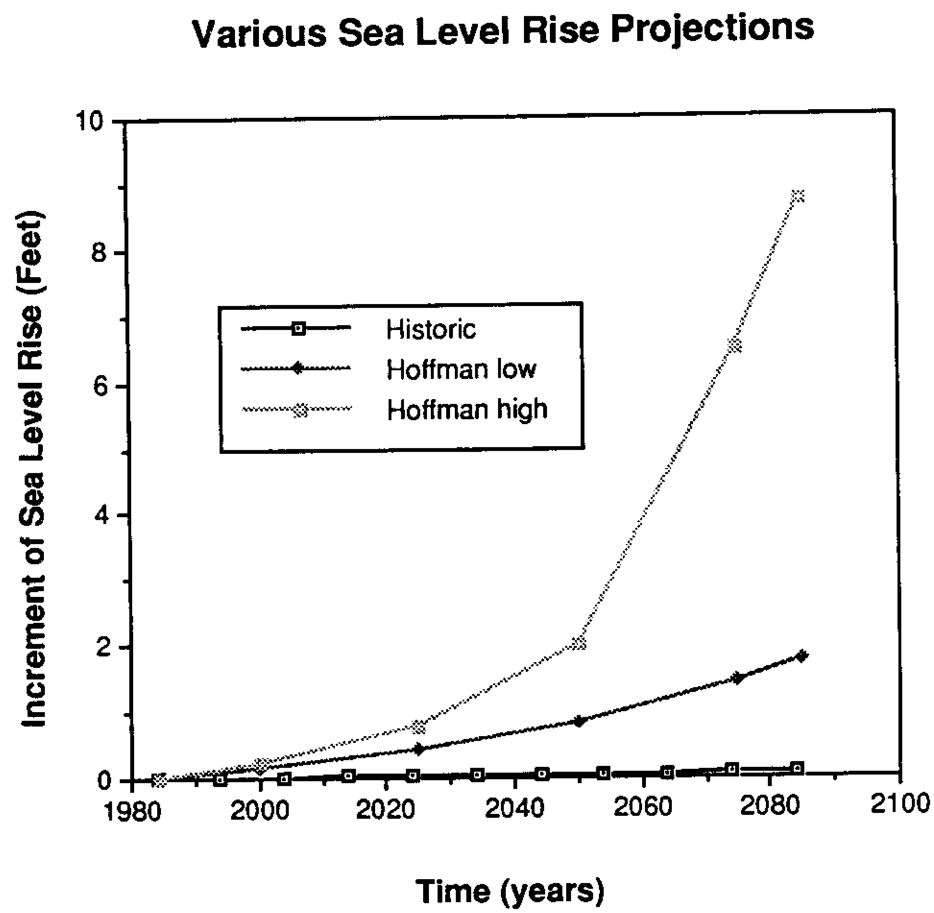

Various Sea Level Rise Projections
Historic
Hoffman low
Hoffman high
Increment of Sea Level Rise (Feet)
10
8
6
4
2
0
1980
2000
2020
2040
2060
2080
2100
Time (years)

FIGURE 2

detail in "Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping", Third Draft, Federal Emergency Management Agency (FEMA), July 1989.

1. Wave Height Analysis

The wave height methodology is based on procedures originally developed by the National Academy of Sciences (NAS) and described in its 1977 report entitled, "Methodology for Calculating Wave Action Effects Associated with Storm Surges." Three major concepts form the basis of the NAS methodology. First, a storm surge on the open coast is accompanied by waves and the maximum height of these waves at any point is directly related to water depth. Secondly, natural and man-made obstructions will dissipate energy; thereby, diminishing breaking wave height. Thirdly, throughout unimpeded reaches between obstructions new wave generation can result from wind action which adds energy; increased wave height being related to distance and mean depth over the unimpeded reach. Wave height analysis was conducted using FEMA computer program "Wave Height Computations for Flood Insurance Studies," Version 3.0, September 1988.

2. Wave Runup Analysis

Stone and Webster Engineering Corporation developed the procedures for wave runup analysis in its "Manual for Wave Runup Analysis, Coastal Flood Insurance Studies", November 1981. It is essentially a composite slope runup procedure relying heavily on data developed by the Corps of Engineers for presentation in the "Shore Protection Manual." The FEMA computer program "Wave Runup," Version 2.0 was employed for this study.

3. Erosion Assessment

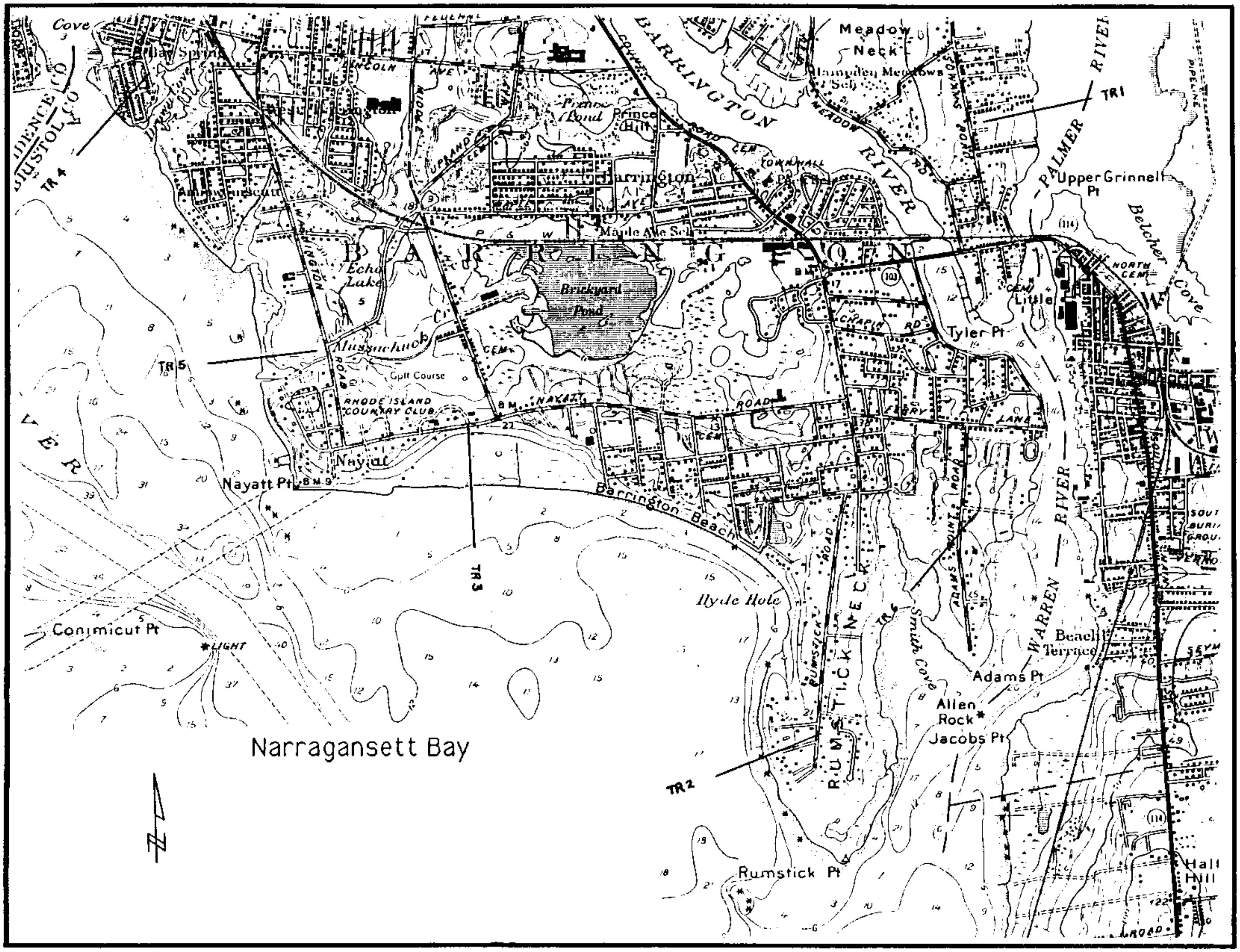
Generally, an erosion assessment must be performed at each location investigated prior to initiating the wave height and runup procedures when coastal sand dunes may have a significant effect on flood levels. At Barrington, there are no significant sand dunes at the sites investigated; therefore, an erosion assessment was not conducted.

B. Methodology

The first step in conducting the hydraulic analysis for this study was to perform a thorough review of relevant information including the draft "Flood Insurance Study (FIS), Barrington, Rhode Island," dated January 1993, and completed by ENSR Consulting and Engineering in December 1992. A field investigation was conducted along the entire Barrington shoreline to become familiar with physical features impacting the flood hazard analysis. (See Figure 3: Transect Location Map is shown)

It was determined that ENSR's analysis currently in review by FEMA's technical consultant, Dewberry and Davis, would serve as an adequate data base as this analysis implements FEMA's latest procedures and uses the best available information.

The base flood or 100-year stillwater level used for existing conditions was presented in the draft Barrington FIS. This level is in close agreement with recent studies conducted by the Corps of Engineers and presented in "Tidal Flood Profiles - New England Coastline," September 1988. For the Barrington and Palmer Rivers, ENSR conducted a storm surge routing analysis to account for stage reductions, due to confined channel and bridge geometries. These levels were adopted for this study. Levels used for existing and sea level rise scenarios are shown in Table 1. Sea level rise conditions were developed in even foot increments to simplify the hydraulic analysis. This assumption is consistent with the relative uncertainty in predicting future sea level, with the goal being to cover the range of predictions made by the research community. In all cases, sea level rise was added to ENSR base flood levels.



Transect Location Map
Barrington, Rhode Island

Figure 3

TABLE 1

BASE FLOOD LEVELS

	Sea Level Rise Condition (ft)	100-Year Stillwater Level (ft, NGVD) Transect 1	Transect 6	Transects 25
Baseline =>	0-ORIG[1]	9.1	13.8	14.8
	1	10.1	14.8	15.8
	2	11.1	15.8	16.8
	3	12.1	16.8	17.8
	6	15.1	19.8	20.8
	9	18.1	22.8	23.8

Notes: [1] Refers to ENSR's 1993 draft FIS analysis currently in review

In order to conduct the analysis of wave height and wave runup for future sea level rise scenarios, some adjustments to the original ENSR transect geometries were necessary. Changes were made, using available mapping, field observations, and best engineering judgment. Some transects were extended to accomodate the increased future sea level rise conditions. For continuity, the offshore wave data, determined by ENSR, was carried throughout the study.

C. Results

With future sea level rise, waves of greater magnitudes will be able to progress further landward due to increased water depths. The net result will be a significant increase in wave crest profile and runup elevations. Increased wave energy will contribute toward added propensity for erosion in the coastal zone. A summary of the hydraulic results for each transect is provided in Appendix A, Table 2 . The table shows the elevation ranges for both the A and V zones for each sea level rise condition evaluated. Also displayed is the shoreward migration of the initial"A/V" zone interface. "V" zones contain wave heights or runup at or exceeding three feet, while "A" zones include waves less than three feet. Substantial shoreward migration of the initial "A/V" zone interface occurs when the ocean stillwater, resulting from sea level rise, further inundates the land mass. The mapping of the sea level rise scenarios is discussed in the following section entitled "Transect Interpretation and Mapping." The increased breaking wave forces will exert significant added damage pressure, especially in exposed areas along Narragansett Bay (transects 2 through 5). Plots of wave heights and runup for all transects for all cases analyzed are contained in Appendix A, Attachment A.

IV. Transect Interpretation and Mapping

A. General

In order to identify the impacts of sea level rise on flooding it was first necessary to analyze the results generated by the wave height and wave runup programs. The various scenarios were plotted and compared with the existing ground profile. The ground profile utilized was based on the 1993 draft FIS with any required adjustments.

Each scenario (i.e. 1 foot sea level rise) was plotted for each transect yielding six plotted profiles. Each transect profile was compared to the existing ground profile. Areas of inundation were identified on each profile and the 100-year coastal flood limit was delineated on 2' contour maps. The 100-year coastal flood limit for the 1 foot, 3 foot, 6 foot and 9 foot sea level rise conditions. The 100-year coastal flood limit for the 1 foot sea level rise condition was plotted because of it was the closest whole foot increment to the historic rate. The 100-year coastal flood limit for the 3 feet sea level rise condition was the next condition plotted since the 2 foot condition already was a close approximation of the 1 foot sea level rise condition. Output from the wave runup was also plotted yielding the runup height above the water level. The maximum runup elevation was determined by adding the highest runup height for a given water level to that water level (See Appendix A, Attachment A: Transect Profiles).

Because of limitations of the wave runup model, special adjustments had to be made to determine the maximum runup. The wave runup model determines the maximum wave runup by calculating successive approximations of hypothetical slope until the generated wave runup heights differ by less than 0.1 foot. For some convex beach profiles and vertical seawalls the runup values will not converge. In this study, there were several situations where the wave runup program would not converge due to a convex profile. For Barrington, there were low bluffs which extended up to a nearly level plateau. Because runup was increased with the addition of sea level rise, runup generated exceeded the elevation of the bluff crest and therefore the program would not converge. For this situation, FEMA adopted a procedure developed by French (1982) for determining the realistic wave runup elevation, (See Figure 4). This study utilized this methodology. Moreover, the wave runup program often calculates a wave runup height which exceeds the maximum ground elevation because it requires the last positive slope to continue indefinitely. However, in reality the wave runup will overtop the maximum elevation and run off before reaching the computed elevation. Therefore, as recommended by FEMA, the maximum wave runup elevation was limited to 3 feet above the maximum ground elevation.

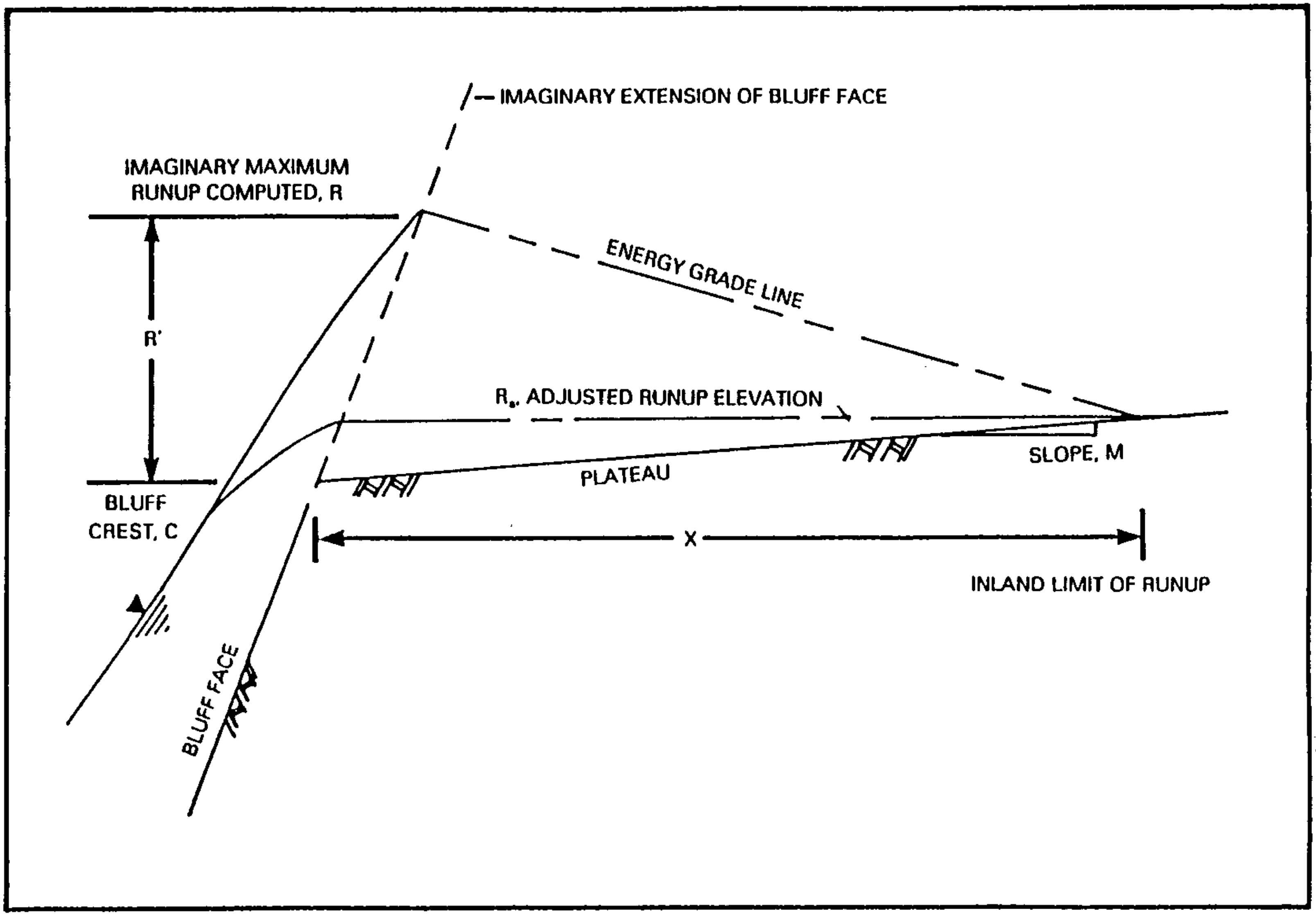
B. Inundation Mapping

Mylar originals of ENSR's topographic maps used for the draft FIS update, were photographed from negatives. ENSR's work maps were derived from original topographic maps developed by Camp, Dresser and McKee, Inc. (CDM) in December 1973. The original scale of these maps was 1"=100' with 2' contour intervals. ENSR consolidated these maps and adjusted the scale of all maps to a scale of 1"=400'. Contours were still kept at 2 foot intervals. These maps were the best available contour maps. For the purposes of this study, the available contour maps provided a sufficient level of detail. One should note that it was never the intent of this investigation to remap the community of Barrington or update the existing FIS. This study was not meant to supersede the published FIS, rather it was intended to address possible impacts of sea level rise that were not addressed or considered in the past study. Therefore, only the limits of the 100-year coastal flood plain were delineated. A and V zones within the flood plain were not identified. In addition, ENSR maps were used so that new baseline 100-year flood limits could be delineated. Only the baseline 100-year coastal flood limits, 1 foot increment, 3 foot increment, 6 foot increment, and 9 foot increment were mapped on mylars.

The mylar flood delineation maps were scanned and digitized. A DXF file was created and used to import the information into an AUTOCAD drawing file. Within the AUTOCAD environment, NED combined all of the drawings into a single drawing file. The AUTOCAD file was once again converted into a DXF type file and imported into ARC/INFO, a Geographic Information System (GIS). Using the ARC/INFO program, NED performed additional editing as well as employed the necessary commands to create ARC/INFO coverages or map layers. These new flood maps were digitally overlayed with existing GIS data obtained from the Rhode Island Geographic Information System (RIGIS). The map layers were used to determine various flood impacts, such as to land use. It should be noted that the RIGIS maps were developed at the 1:24000 scale quadrangle level thus one should realize the limitations associated with using these layers with respect to NED's larger scale maps. NED was aware of the distortion and limitations, but determined that this gross level of analysis was adequate for assessing the potential flooding impacts due to sea level rise. The next section identifies particular areas of concern as well as discusses some of the flooding impacts.

FIGURE 4

From FEMA, "Guidelines and Specifications for Wave Elevation Determination and V-Zone Mapping", Third Draft 1989, p 51, Figure 12



Runup on Low Bluffs

V. Impacts of Sea Level Rise

A. General

Although, sea level rise will cause a multitude of impacts on the coastal shoreline, the potential impacts resulting from flooding is the primary focus of this study. Sea level rise will cause both greater areas of land to be inundated as well as elevated flood levels. Therefore, land which is presently in a minimal flood risk area will experience a greater risk from flooding as sea level rises. In addition, sea level rise will influence landward migration of shoreline features such as wetlands and barrier beaches as well as the saltwater marsh zone. Sea level rise could also affect groundwater supply.

B. Identification of Potential Flooding Impacts

1. General

Besides elevated flood levels, sea level rise will expand the flood impact areas. (One should note that this study did not delineate between A and V zones, but rather delineated only the 100-year coastal flood limits. Based on a gross estimate of additional flood impacted areas, Table 2 presents the percentage increase associated with the additional increment of sea level rise.

TABLE 2

% Increase in Flood Impacted Areas

Sea Level Rise Stillwater Condition (ft, NGVD)	% Increase in 100-Year Coastal Flood Area
1 foot sea level rise	9.7
3 foot sea level rise	30.4
6 foot sea level rise	52.0
9 foot sea level rise	72.7

Flood delineations accounting for sea level rise reveal that generally the flatter sloped areas will receive the greatest impact on land use and structures. Overall in terms of land use as provided by RIGIS, areas predominantly designated as residential will experience the greatest levels of inundation. These areas will experience both increased levels of flooding from higher flood elevations and wider flood limits as sea level rises. It should be noted that RIGIS land use and land cover data was developed from 1:24000 scale stereo aerial photography.

2. <u>Existing Flood Conditions.</u>

The Meadows Neck area, near Transect #1 with its extremely flat terrain will be particularly susceptible to increased flooding with sea level rise. This area already experiences significant flooding at current 100-year coastal flood conditions. The area south of the railroad (a potential future bicycle path) is a highly flooded area with numerous structures affected. Houses immediately adjacent to Transect #1 are also subject to inundation, however the area is not densely populated with houses.

At Transect #2 thru #5, flooding is caused by wave action from Narragansett Bay. Areas across these transects are primarily beach property with some house structures. At Transect #2 on Rumstick Neck there are about 16 houses affected by the 100-year coastal flood. Between transects #2 and #3, only beach areas will be impacted. Between transects #4 and #5, particularly near Transect #4, the Lantham Park area, many houses are located within the 100-year coastal flood zone. Since Transect #6 is not in a densely populated area, not many structures will be affected by sea level rise. For photographs of the transect areas see Figures 6A thru 6F.

Figure 6A: View Near Transect No. 1.

Figure 6B: View Near Transect No. 2 from Dead End Turnaround of Holly Lane.

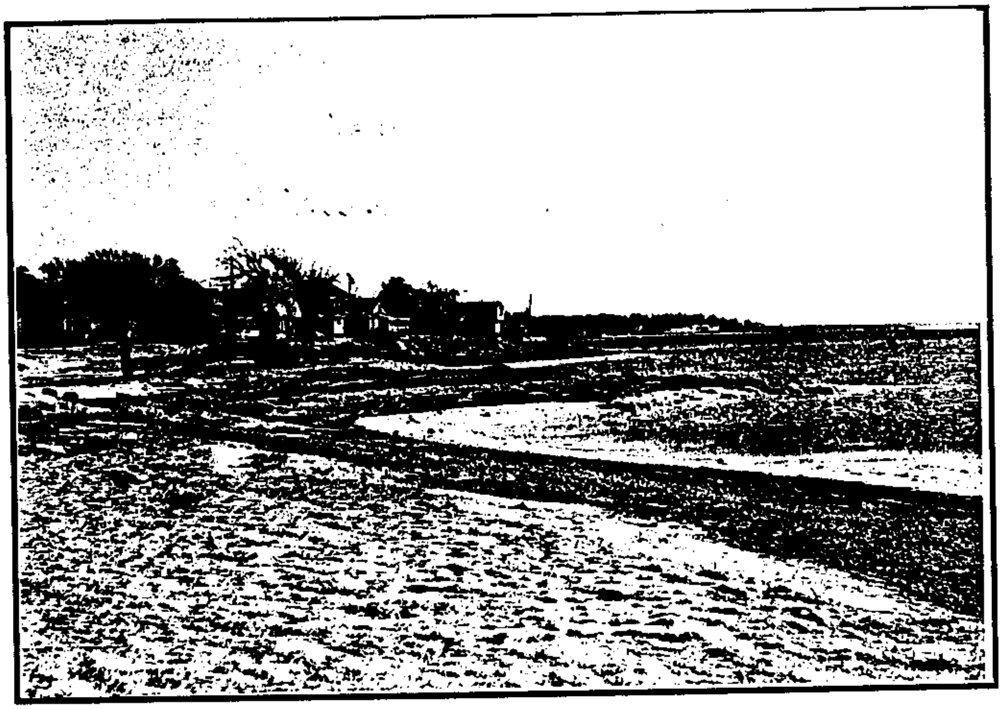


Figure 6C: View Near Transect No. 4 from Lantham Park.

Figure 6D: View Near Transect No. 3 looking seaward from Rhode Island Country Club; Golf Course.

Figure 6E: View Along Transect No. 5 looking seaward on Lighthouse Lane.

Figure 6F: View Near Transect No. 6 from Private Road.

3. Additional Flood Potential Areas Due to Sea Level Rise

Figures 7 illustrates, the effect that sea level rise will have on the 100-year coastal flood limits. The different color shaded regions represent the areas of additional 100-year coastal flood plain for the various sea level rise increments. As sea level rises from 1 foot to 9 feet, the area of the shaded regions gradually increases illustrating wider flooding impacts. Each successive shaded region represents the additional flooded area from the previous flooded area. For instance, the yellow shaded regions represent those additional flooded areas due to 1 foot sea level rise beyond the existing 100-year coastal flood limit.

The study also found that upper riverine areas will experience greater flooding because the flood limits are based upon stillwater elevations. Furthermore, because of elevated sea levels, wave runup effects will be more prevalent. The 100-year coastal flood delineations demonstrate that the amount of sea level rise directly influences the level of flooding.

In order to facilitate one's understanding of the flooding impacts for the various sea level rise increments, impacts were divided into two major ranges: 1) 1-3 foot; and 2) 6-9 foot. The 1 foot range is the closest approximation for the historic trends whereas the 6-9 foot range represents a more drastic increase in sea level. Flooding impacts were grouped into ranges for ease of discussion.

For the most part this study focuses on addressing flood impacts near the various transects. As Figure 7 illustrates, additional landward inundation due to 1 foot and even 3 foot sea level rise does not increase appreciably. It is not until sea level rise increments reach the 6-9 foot range that there are significantly larger areas of potential flood impacts. However, there are pockets of flood areas scattered about Barrington, particular those areas near the transect locations that warrant further discussion. The next section will discuss and attempt to identify some of these potentially flooded areas in the context of land use effects.

4. Land Use Effects

Transect #1: 1-3 Foot Range

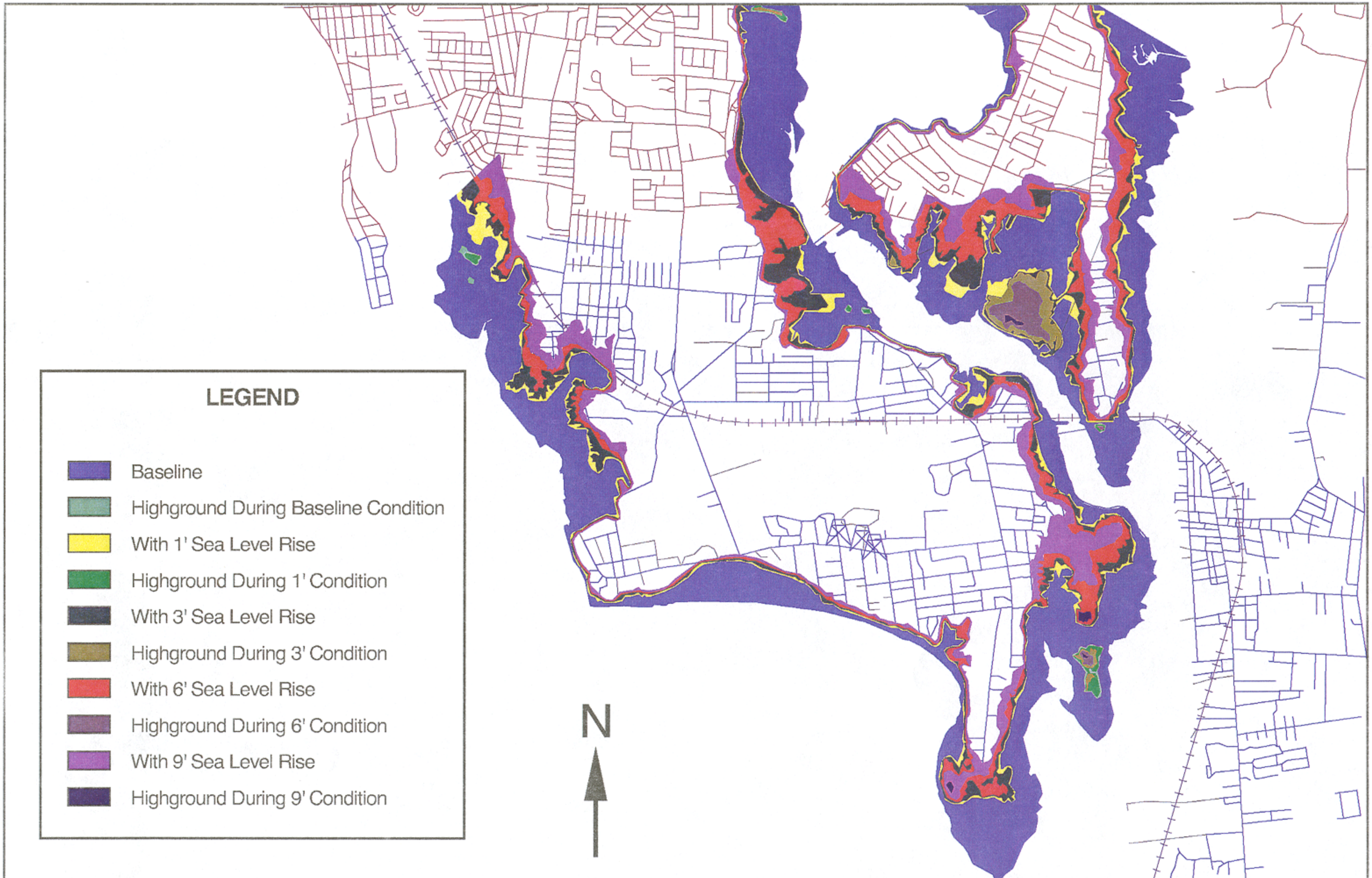
Because the Meadow Neck area is already in a particularly flood sensitive area with its flat terrain, increasing the sea level by 1 to 3 feet will create additional flood impacts to land use. At this sea level range, it does not appear that new categories of land use will be affected. However, there will be additional impacts to residential zoned area and wetlands designated areas. (See Figure 8.) Additional residential structures along Orchard and Garden Avenue will be within the 100-year coastal flood zone.

Transect #1: 6-9 Foot Range

At the 6-9 foot range, the sea level rise will significantly increase both the magnitude and flooding area for the Meadow Neck area. Portions of Orchard Avenue zoned for agricultural use will be affected. More critical, however is the area located just south of New Meadow Neck. This flood impact is within the vicinity of the intersection of Linden Road and GreenBrier Drive and includes Lafayette Road and Nathaniel Road.

Transect #2: 1-3 Foot Range

At this range of sea level rise, the 100-year coastal flood limits will not significantly increase at the Rumstick Neck area. Therefore, this primarily residential zoned area will not experience an appreciable amount of flood impacts. Areas south of Rumstick Neck Road to Rumstick Neck consisting primarily of wetlands designated use, already experience flooding due to the current 100-year coastal floods. Sea level rise will contribute primarily to higher flood levels.



Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.

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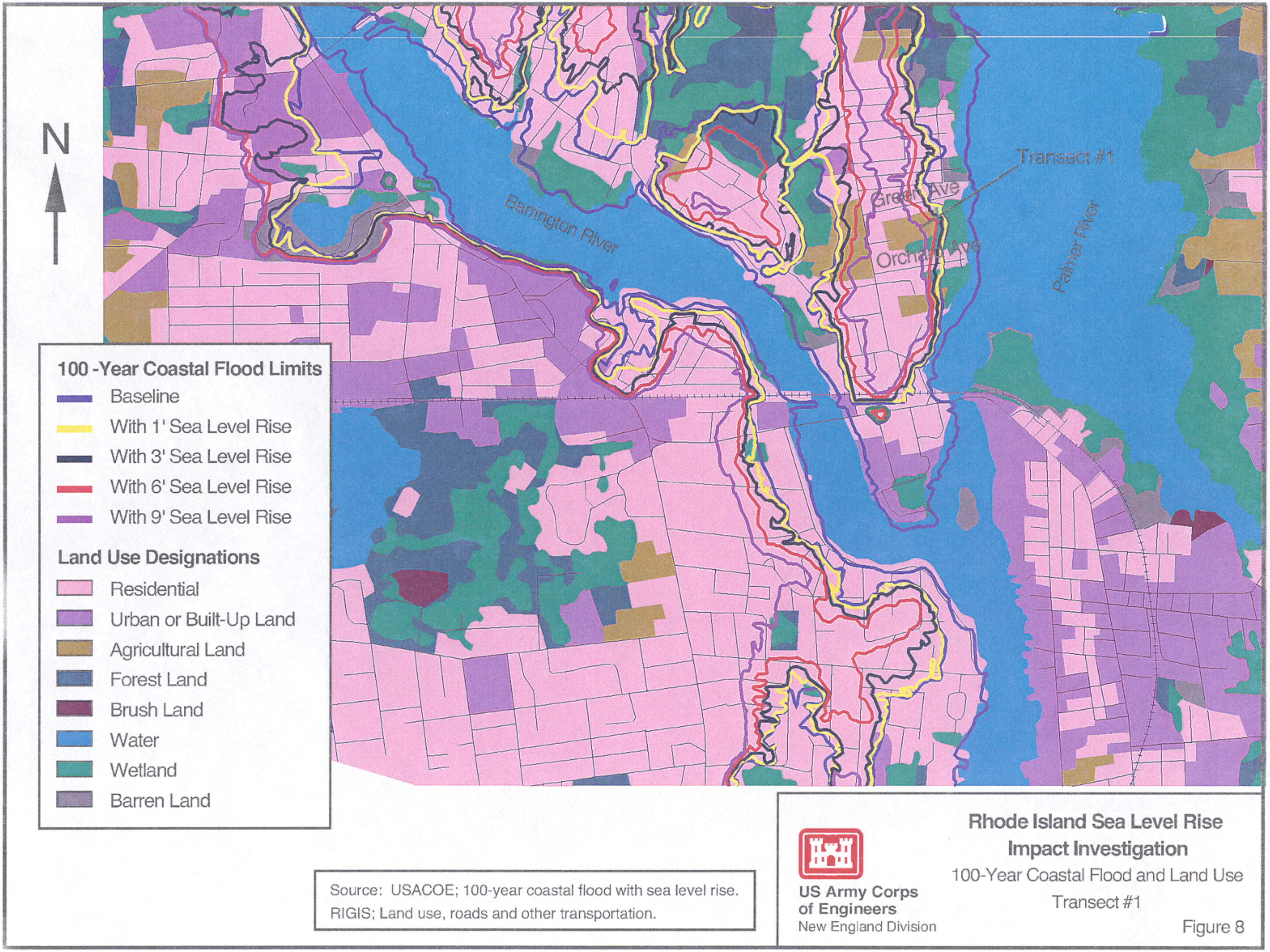
100-Year Coastal Flood Areas

Barrington, Rhode Island

Figure 7



Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.

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Rhode Island Sea Level Rise Impact Investigation

100-Year Coastal Flood and Land Use

Transect #1

Figure 8

Transect #2: 6-9 Foot Range

At the 6-9 foot range, residential structures south of Strawberry Drive will be inundated. Many of these structures would not normally be within the 100-year coastal flood, particularly between Holly Lane and Strawberry Drive. (See Figure 9.)

Transect #3: 1-3 Foot Range and 6-9 Foot Range

With sea level rise at all these ranges, there will not be a significant increase in the extent of the 100-year coastal flood plain, since the terrain beyond the existing 100-year flood plain rises quickly. However, as Table 1 previously indicates, the flood levels will increase with sea level rise. The flood zone here will continue to encompass a beach. The primary area of impact will be the Rhode Island Country Club golf course. (See Figure 11.)

Transect #4: 1-3 Foot Range

Since most of the Lantham Park area is already currently within the 100-year coastal flood zone, when sea level rise reaches the 1-3 foot range, there will be greater potential for flood related impacts. At present 100-year conditions, mostly residential use, other urban use and wetland designated use will be affected. With a sea level rise of 1-3 feet, some forest designated land use areas will also be affected. The Lantham Park area is particularly susceptible to flood related damages because it is densely populated with residential structures. With sea level rise, these floodplain structures will be exposed to even greater flood risks and damages, because of the additional flood levels. At this range, the 100-year coastal flood zone near Transect #4 is bounded by the Barrington corporate boundary with East Providence to Ocean Avenue and almost to the abandoned railroad tracks. (See Figure 10.)

Transect #4: 6-9 Foot Range

At this range, the remaining area adjacent to the west side of the former railroad tracks will be within the 100-year coastal flood zone. An area just east of the former railroad tracks will also be within the 100-year coastal floodplain. This additional area is mostly forest land occupied by the Haines Memorial State Park.

Transect #5: 1-3 Foot Range and 6-9 Foot Range

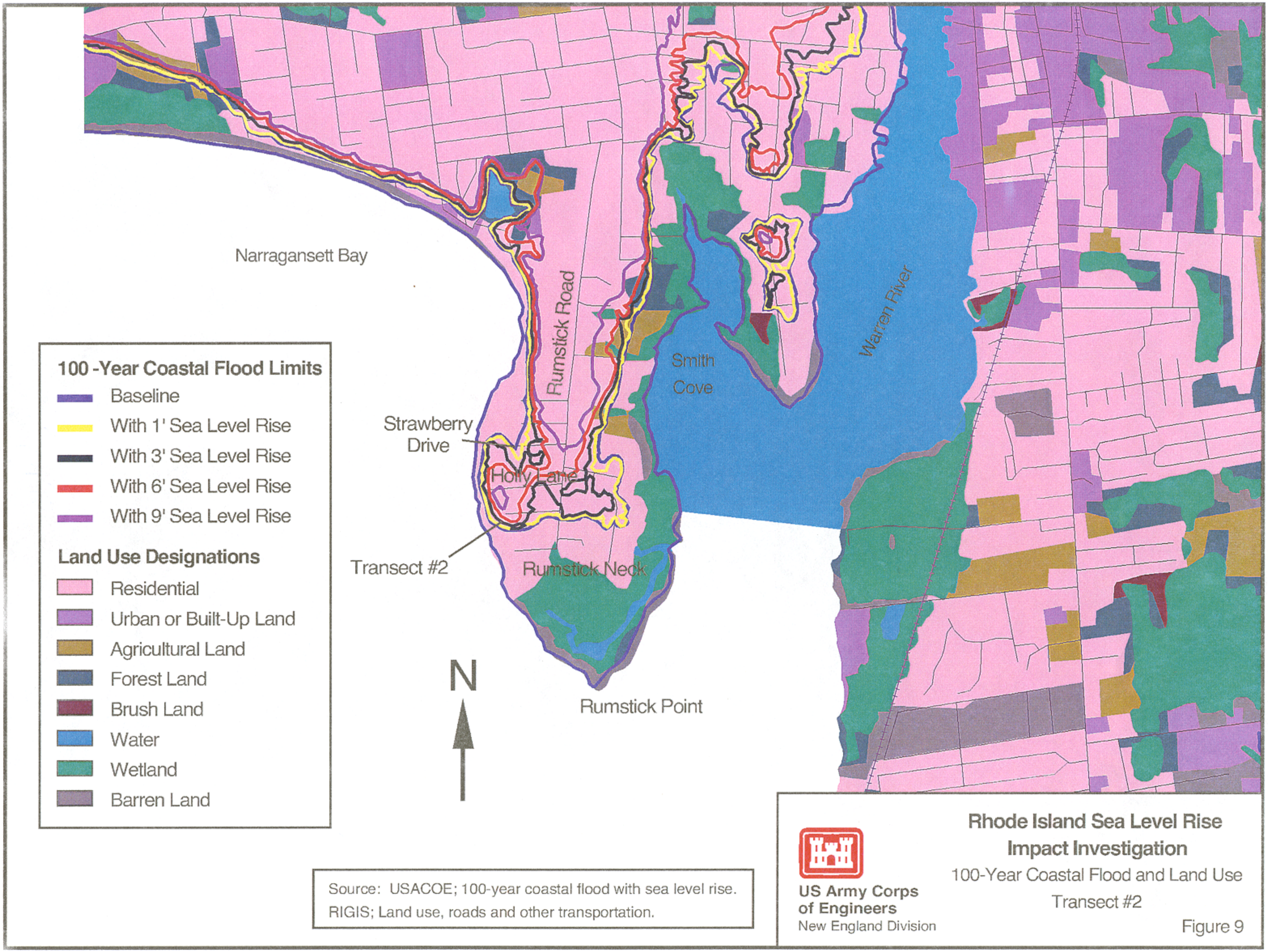
With the current 100-year coastal flood zone, residences along Light House Lane will experience flood impacts. Therefore, at the 1-3 foot range of sea level rise, these houses will have an even greater potential for flood related damages, due to the higher flood levels. Likewise, at the 6-9 foot range, flood levels will be even higher. The overall width of the flood zone will not really increase significantly. Forested land adjacent to the southwest portion of Echo Lake will also be within the 100-year floodplain, however no homes within this area will be affected. (See Figure 11.)

Transect #6: 1-3 Foot Range

At the 1-3 foot range, perhaps a half dozen residential structures located near Adams Point and north of Bourne Lane will be within the 100-year coastal flood limits. Since there is higher ground elevations near areas along Adams Point Road from Eddy Court to Hannah cirle, these structures should be relatively safe from flooding. (See Figure 12.)

Transect #6: 6-9 Foot Range

Significant flooding impacts to land use occur when sea level rise reaches these levels. Most areas along Adams Point Road from Ferry Lane will be inundated.



Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.

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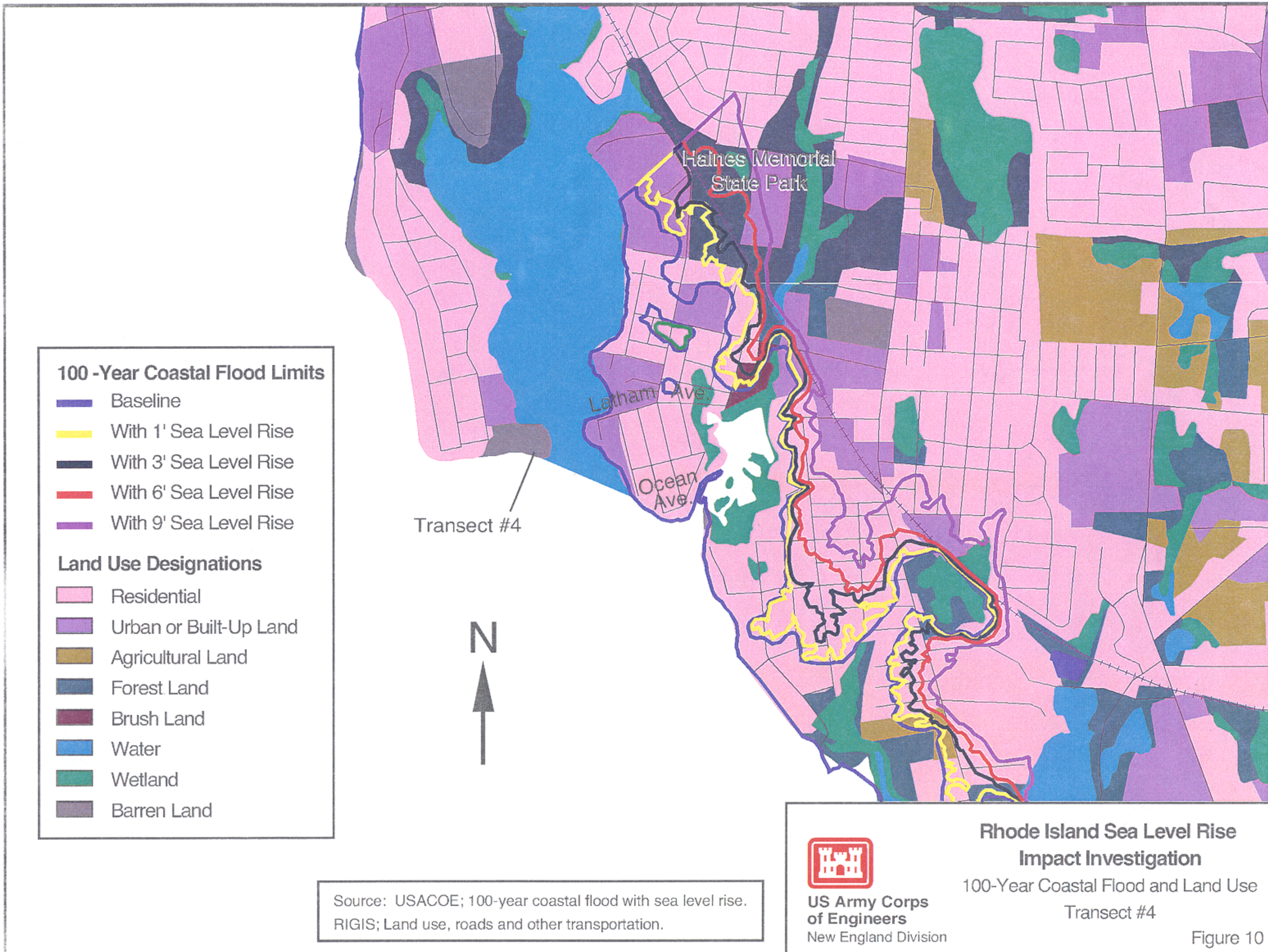
Rhode Island Sea Level Rise Impact Investigation

100-Year Coastal Flood and Land Use

Transect #2

Figure 9



Haines Memorial State Park
Latham Ave.
Ocean Ave.
Transect #4
N
100 -Year Coastal Flood Limits
Baseline
With 1' Sea Level Rise
With 3' Sea Level Rise
With 6' Sea Level Rise
With 9' Sea Level Rise
Land Use Designations
Residential
Urban or Built-Up Land
Agricultural Land
Forest Land
Brush Land
Water
Wetland
Barren Land
Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.
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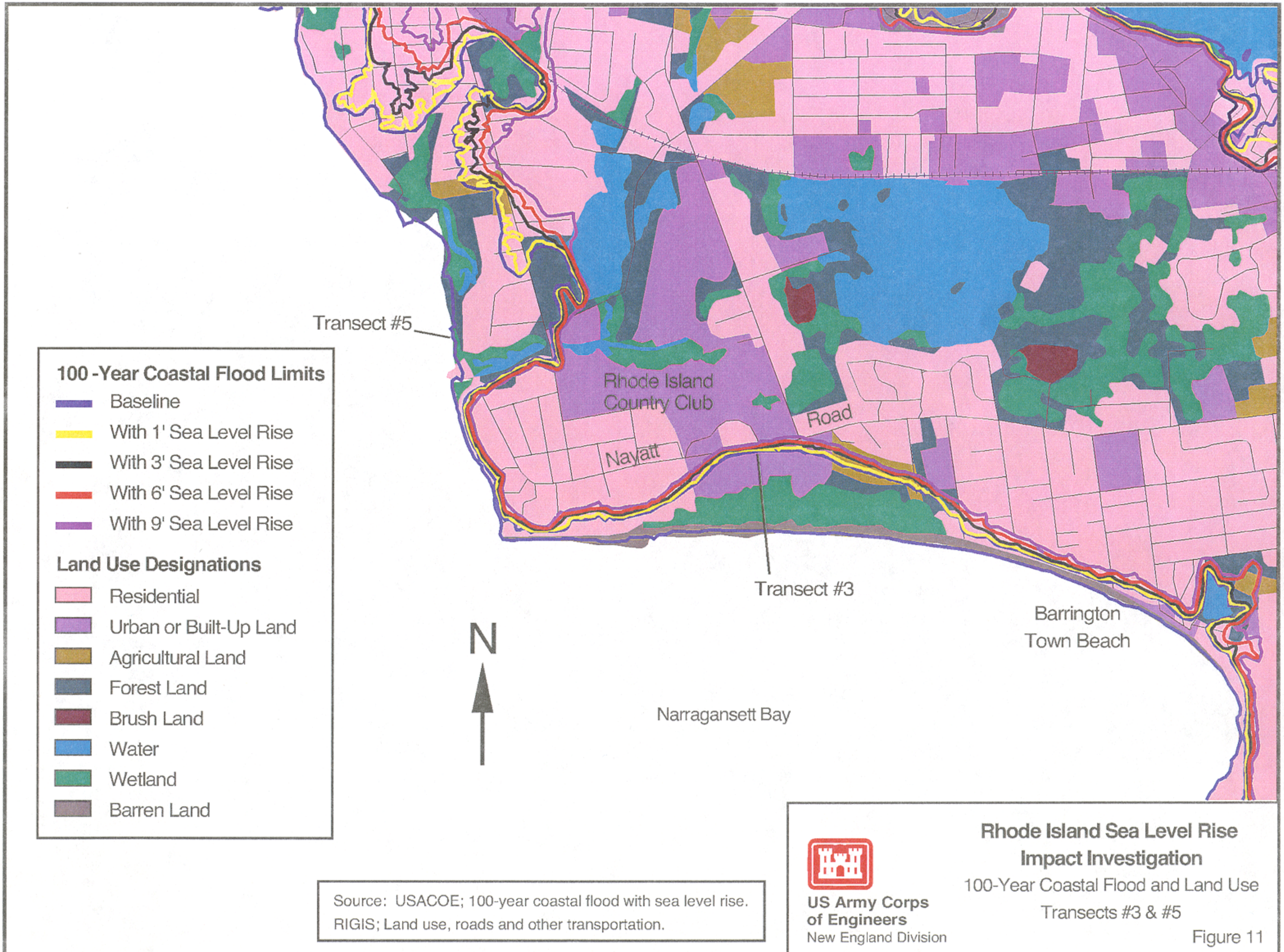
New England Division
Rhode Island Sea Level Rise Impact Investigation
100-Year Coastal Flood and Land Use
Transect #4
Figure 10



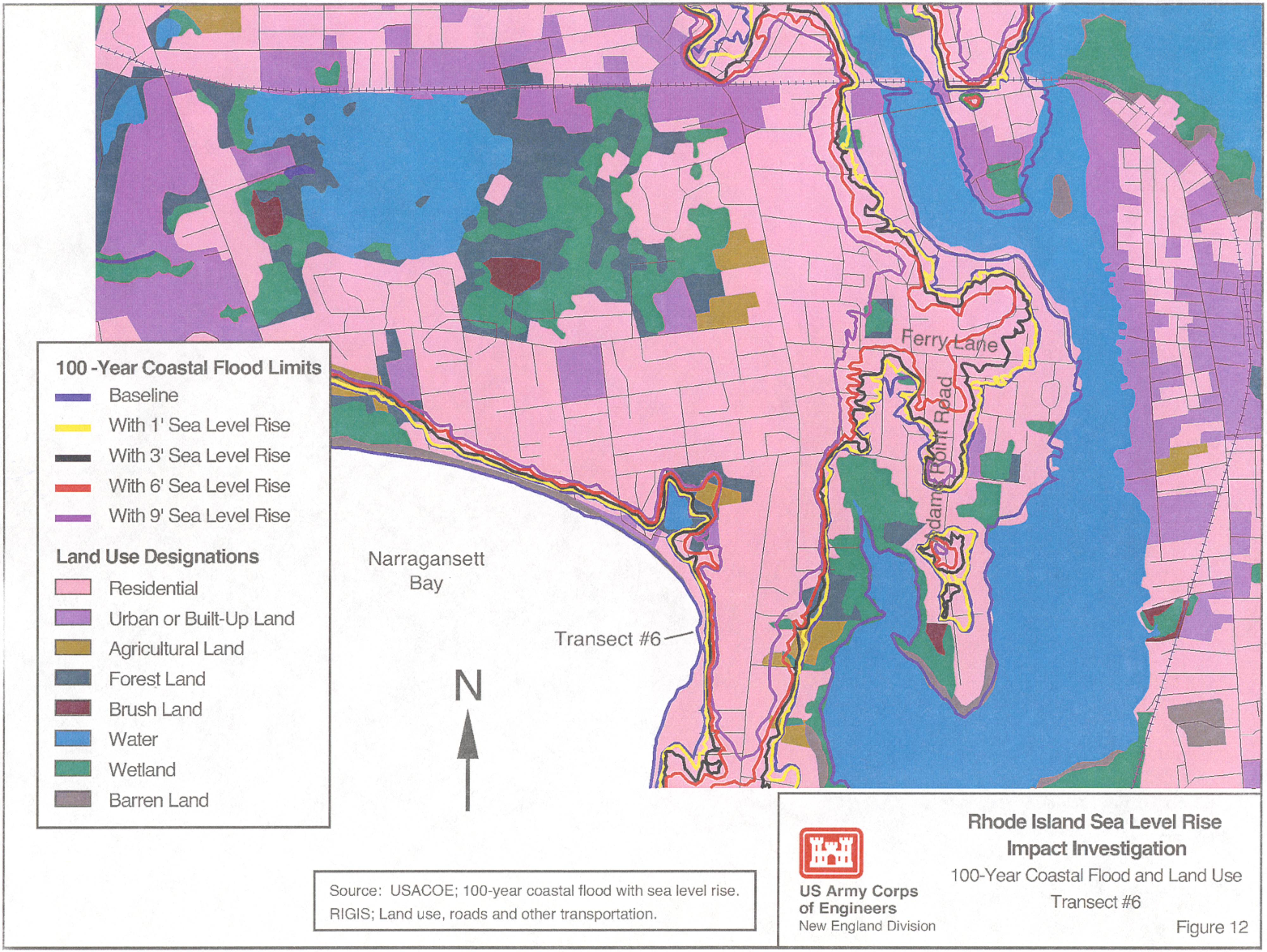
Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.

Rhode Island Sea Level Rise Impact Investigation

100-Year Coastal Flood and Land Use

Transects #3 & #5

Figure 11



Source: USACOE; 100-year coastal flood with sea level rise.
RIGIS; Land use, roads and other transportation.

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Rhode Island Sea Level Rise Impact Investigation

100-Year Coastal Flood and Land Use

Transect #6

Figure 12

C. Salt Marshes

1. Salt Marsh Vegetation

Before summarizing the effects of sea level rise on salt marshes, a brief description of salt marsh plant zonation is necessary. Salt marshes are generally classified into two types (high marsh and low marsh) based on the frequency of tidal flooding and vegetation type. The low marsh, or regularly flooded marsh, occurs roughly between the level of mean high water (MHW) and mean low water (MLW). In general, its elevational range is wider where the tidal range is greater (McKee and Patrick, 1988). The dominant vegetation in the low marsh is the tall form of salt marsh cordgrass (Spartina alterniflora). The high marsh, or irregularly flooded marsh, occurs between about MHW and the level of the highest astronomic tides. The dominant vegetation types in the high marsh are salt meadow grass (Spartina patens), spike grass (Distichlis spicata), and black grass (Juncus gerardi).

2. Sea Level Rise Effects

There are three majors ways that sea level rise can disrupt coastal wetlands: inundation, erosion, and saltwater intrusion (Titus, 1988). These factors produce three possible outcomes as identified by Orson et al. (1985; cited by Phillips, 1986):

a) marsh expansion when sedimentation exceeds submergence;

b) marsh drowning when sediment supply and accretion is less than the rate of coastal submergence (a combination of sea level rise and land subsidence); and

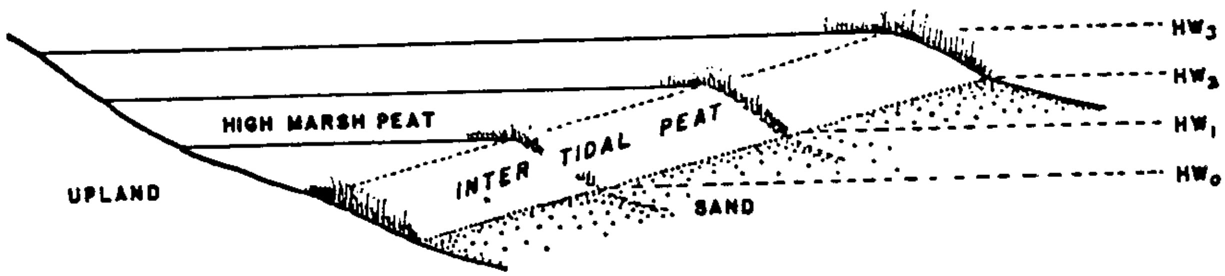
c) marsh maintenance if sedimentation balances submergence.

3. Marsh Expansion and Maintenance

Marsh accretion occurs through a combination of building up of salt marsh plant material and trapping of coastal, riverine, and upland sediments. A marsh can expand or maintain itself where there is sufficient sediment supply to keep pace with the rate of sea level rise (Nixon, 1982; Titus, 1988). Nixon (1982), in "The Ecology of New England High Salt Marshes: A Community Profile," summarized the response of salt marshes to sea level rise. According to Nixon, the most recent, and generally accepted, view of how marshes adjust to sea level was developed by Redfield (1972) in his classic study of Barnstable Marsh on Cape Cod. This synthesis combines the earlier theories of N.S. Shaler (1886) and B.F. Mudge (1862) on marsh development with new research and an understanding of the role of sea level rise. Nixon summarized Redfield's findings as follows: "With a rising sea level and a sufficient sediment supply...the intertidal S. alterniflora peat extended progressively out from the shore and at an upward slope over an aggrading sand and mud deposit. The high marsh peat then formed over the intertidal peat as a wedge which thinned as it expanded toward the upland and the seaward edge of the marsh." In other words, salt marshes adjust to sea level rise by expanding inland and waterward and increasing in elevation through accumulation of sediments and plant biomass. This process is shown in Figure 5. Marsh maintenance occurs when the marsh increases in elevation, but does not expand at its upland or seaward limits. Marsh expansion occurs when the marsh grows over the adjacent upland or aggrading coastal sand. Most seaward growth occurs with younger marshes which have not filled their basin.

The process of marsh accretion and expansion is dependent on a sufficient supply of mineral sediments to supplement and condition the substrate (Bricker-Urso et al., 1989). In Rhode Island, the high marsh accretion rate has been about equal to the rate of sea level rise and the low marsh accretion rate has been slightly higher (Bricker-Urso, 1989). Nixon (1982) reported that salt marshes accretion rates have been recorded as high as 50 millimeters per year in newly forming marshes and theorized that, given an adequate sediment supply, the marsh grasses are capable of adjusting to rapid rates of sea level rise.

Model for Salt Marsh Development



Redfield's model for salt-marsh development over accumulating sediment on a sand flat and over the upland under the influence of rising sea level (Redfield 1972). HW refers to mean high water at various times during development.

From Nixon, 1982, "The Ecology of New England High Salt Marshes: A Community Profile.", Figure 1.

FIGURE 5

4. Marsh Drowning

Where the supply of sediment is insufficient to allow the marsh to keep pace with sea level rise, eventual submergence or drowning of the marsh can occur. The process of marsh drowning can begin with subtle changes in the vegetation. Increased tidal flooding associated with low accretion rates relative to sea level rise apparently resulted in the replacement of the typically dominant salt marsh plants (e.g., salt meadow grass and black grass) by forbs and stunted salt marsh cordgrass at the Wequetequock-Pawcatuck marshes in Connecticut. This has resulted in a lowering of marsh productivity and still lower projected accretion rates (Warren and Niering, 1993). Over time, more significant changes in the salt marsh can occur where accretion does not keep pace with sea level rise.

In the total absence of surface accretion, the frequency and duration of marsh inundation would increase causing the marsh to evolve to progressively wetter forms and eventually open water. A rise in sea level would cause a corresponding increase in the elevation of the tidal datums (e.g., MHW and the highest astronomic tide level) which delimit the major salt marsh boundaries. The seaward limit of the low marsh would be exposed to increased erosional forces preventing the low marsh from increasing in size laterally toward the ocean or bay. Mean tide level would increase in elevation to claim the low marsh as unvegetated intertidal, then open water habitat. MHW, which roughly corresponds to the low marsh/high marsh border, would move up in elevation, migrating across the high marsh and changing it to low marsh, until the high marsh drowned from too high a frequency and duration of flooding. High marsh would be completely eliminated when the level of MHW exceeded the elevation of the highest existing area of high marsh. Because of the very gentle slope and elevational range of the high marsh, the change from high marsh to low marsh and open water would occur relatively quickly. The high marsh would be replaced by low marsh until the frequency of flooding exceeded the threshold for low marsh, then only open water would remain with a fringing salt marsh along the shoreline.

5. Marsh Maintenance and Transition

Where a sediment supply is presently not sufficient for marsh expansion the marsh will temporarily adjust to increased sea level rise. The following factors, interrelated with sediment availability, affect the ability of a salt marsh to keep pace with sea level rise: 1) erosion at the seaward edge; 2) slope of the adjacent upland; and 3) the rate of sea level rise. The quantity of channels, ditches, and pannes on a marsh also influences the ability of the marsh to keep pace with sea level rise by providing an increased edge for exposure to erosional forces (Phillips, 1986).

Erosion of the seaward edge limits the ability of the marsh to expand outward in response to sea level rise. The amount of erosion of the seaward edge of the marsh is the result of a balance between the magnitude of sea level rise and the rate at which new sediment is supplied. If the rate of sea level rise exceeds the rate of accretion, the seaward edge of the marsh will erode. That material eroded from the edge will be spread across the marsh surface and the nearshore zone to increase its elevation (Reed, 1988). Bruun (1962) developed a method now known as the Bruun Rule to determine the erosion rate due to sea level rise. As summarized by Phillips (1986), "The Bruun Rule holds that, for a shoreline in longshore equilibrium, a given rate of sea level rise will result in shoreline erosion sufficient to deposit sediment in the nearshore zone to a depth equal to sea level rise." (The nearshore zone is the zone along the shore affected by waves.) Applying the Bruun Rule to marsh erosion, the quantity of material eroded from the marsh edges would have to be sufficient to cover the nearshore area (in some cases the creek bed) for the seaward edge of the marsh to maintain or expand its lateral extent before marsh accretion can occur.

The change in marsh area with sea level rise also depends on the slope of the marsh and adjacent upland. If the slope were constant, the area lost to marsh drowning would be equal to the area gained by landward encroachment of the highest astronomic tides (upper limit of salt marsh). However, the slope of the marsh is generally less steep than the slope of the upland (Titus, 1988). Given a constant erosion rate caused by sea level rise, the accretion rate must be higher to maintain the existing marsh area where the upland slope is greater (Phillips, 1986). Therefore, even with sediments supplied by erosion of the marsh edge, a decrease in marsh area would occur unless the rate of accretion exceeded the rate of submergence.

6. Effects on the Marshes of the Town of Barrington

As previously discussed, salt marshes can adjust to sea level rise with sediment input. Using the difference between mean high water and mean spring high water as a rough estimate of the vertical range of high marsh at Nayatt Point in Barrington the vertical range of high marsh was estimated at 1.1 ft. (NOS, 1992). Since the ability of a marsh to keep pace with sea level rise is dependent on sediment supply, site-specific analyses of the watershed and coastal sediment inputs would be required to estimate the reaction of the marshes in Barrington to sea level rise. However, without site-specific analysis, it is expected that the elevation of the marsh surface could keep pace with the historic rate of sea level rise (~1 ft/100yr) which is approximately equal to the existing vertical range of high marsh (Nixon, 1982; Reed, 1988; Bricker-Urso, 1989).

Without site-specific analysis, it is not possible to estimate the effects of sea level rise of 2 or 3 feet for this study, although, in general, the higher the rate of sea level rise the greater the likelihood of marsh drowning.

Under the 6 ft/100 yr (18 mm/yr) and 9 ft/100 yr (27 mm/year) sea level rise scenarios, major reductions in the area of salt marsh would most likely occur since the quantity of sediment input would have to be very high. However, if the sediment supply were sufficient, the marsh could probably partially adjust to even these extreme rates of sea level rise.

If no accretion occurred almost all high marsh would be eliminated with a 1.1 ft. rise in sea level. Likewise, assuming that the low marsh extends from mean tide level to mean high water a vertical extent of 2.2 ft., all low marsh within the footprint of existing salt marsh would not be eliminated until sea level rise exceeded 3.3 ft. With 3 to 9 feet of sea level rise only open water and a thin salt marsh fringe would be present.

7. Effects at the Study Transects

Predictions can be made about the effect of sea level rise on the salt marshes of Barrington at the study transects. Transects 1, 3, and 6 pass through salt marsh.

Transect #1 passes through a thin fringe of salt marsh of about 75 feet in width, then through about 150 feet of common reed marsh (Phragmites australis) along the west bank of the Palmer River. The slope is fairly shallow until about 270 feet from the edge of the marsh where it increases sharply at the edge of fill. Salt marsh would probably expand into the common reed marsh with sea level rise without losing salt marsh area although the fringing common reed marsh would be lost. Depending on the rate, salt marsh area would probably not be lost until sea level rise exceeded 6 feet.

Transect #3 passes through a small barrier beach and about 700 feet of salt marsh. Nayatt Road and some houses are located behind the marsh. This salt marsh/barrier system would respond to sea level rise in the typical overwash transgressive sequence. Storms that overtop the barrier beach cause the beach to migrate inland onto the marsh. Sediment washed over the beach during these events supplies the marsh, enabling it to keep pace with sea level rise. Because of the developed upland behind this system, however, the salt marsh would decrease in area with landward migration of the barrier beach.

The salt marshes along Rumstick Point and Adams Point are highly susceptible to erosion with sea level rise. Phillips (1986) found that similar peninsular points in Delaware experienced rapid truncation with sea level rise. This is due to the focusing of wave energy on the point through refraction. Erosion of sediment from these points could supply the salt marsh in Smith Cove where Transect #6 is located with sediment to enable it to keep pace with sea level rise. The upland slope along Transect #6 is relatively steep, therefore, sediment input would have to be high for this portion of the marsh to keep pace with sea level rise. The funnel shape of this marsh should help it to accumulate sediment and keep pace with sea level rise and expand seaward, but the level of development on the upland edge would prevent it from expanding landward.

D. Groundwater

Although a comprehensive evaluation of the impacts of sea level rise on groundwater is beyond the scope of this study, the report does discuss some of the general impacts which should be of concern to the State. Scientific literature has suggested that even relatively small increases in sea level could cause significant impacts. The saltwater wedge through estuaries and tidal rivers could advance as a result of sea level rise, causing saltwater intrusion of coastal aquifers. Some researchers have indicated that a sea level rise of 10 centimeters (3.9 inches) could cause a landward shift of the saltwater wedge by as much as 1 kilometer (0.62 miles) (NRC, 1987). Consequently, groundwater supplies could be threatened by saltwater intrusion by only small increases in sea level. Although this study did not quantify the salinity intrusion, it is apparent that even with a sea level rise rate of about 1 foot/100 years, the increased salinity levels could cause dramatic impacts to groundwater supplies.

For the Town of Barrington, a groundwater reservoir located in the vicinity of the Barrington Town Beach could be potentially impacted by sea level rise. Determining the amount of potential salinity intrusion was beyond the scope of this study and would require further more detailed investigations.

VI. Conclusions

Based on the previous sections, several conclusions can be drawn as to the associated impacts that increased sea level rise could have on a coastal community such as Barrington, Rhode Island.

This study focused on determining the potential flooding impacts under several different whole foot sea level rise increments. This study has found that variations of sea level rise will result in different magnitudes of flooding impacts and environmental impacts. However, the analyses have demonstrated that in any sea level rise scenario, there will be some amount of increased risk to flooding. Overall, as the magnitude of the sea level rise increment increases there will be a corresponding increase in the 100-year coastal flood limits and stillwater elevations.

This study has found that impacts due to sea level rise are extremely site specific. Nevertheless, this case study of Barrington provides a useful tool for regulatory, or planning agencies in that it identifies coastal areas that are particularly susceptible to sea level rise impacts. Because the community of Barrington has a diverse mix of coastal features, natural resources, and developmental characteristics, it provides a good example of the range of impacts that could potentially occur. This study has revealed that sea level rise effects vary considerably according to such factors as: a) slope; b) coastline and topography; and c) land use, i.e. undeveloped, developed, etc.

For Barrington, the study found that low, flat terrain areas will experience the most flooding since the hydraulics of Barrington is primarily governed by wave height. Most of the areas affected are beach areas, or wetland designated areas which have very flat slopes. Generally, those areas which are currently within the 100-year coastal flood limits will have the greatest potential for flooding impact associated with sea level rise. Those areas along the Meadows Neck Area (Transect #1) and the Lantham Park Area (Transect #4) will be particularly susceptible to flood related damages because of the density of residential development. There are also commercial structures that may contain stored materials, warehouse goods, equipment and machinery which could be damaged by flood waters in addition to any flood related structural damage.

Undeveloped areas such as the Barrington Town Beach may also experience flooding, but flood damages would be of a different nature. In addition, during severe flooding there is always the possibility of significant beach erosion requiring future beach nourishment.

In addition to variations in flooding impacts, different magnitudes of sea level rise will affect salt marsh development. Although, salt marsh development is extremely site specific and dependent on sediment supply , this study found that generally the salt marshes in Barrington, near Transects #1, #3 and #6 should be able to maintain their current elevations until sea level rise exceeds 6 feet. Specfic salt marsh effects based on increments of sea level rise greater than 6 feet were beyond the scope of this study. However, because of the developed uplands behind the various salt marsh systems in Barrington particularly Transects # 1 and #6, the salt marsh would decrease in areas with landward migration of the barrier beach. Generally, under higher rates of sea level rise, there is a greater likelihood that marsh drowning would occur assuming the sediment supply was deficient. However, if sediment supply were sufficient, the marsh could partially adjust to even these extreme rates of sea level rise.

This study also identified a groundwater reservoir located in the vicinity of the Barrington Town Beach could potentially be impacted by sea level rise. At this location, there is the potential that sea level rise could increase saltwater intrusion of coastal aquifers causing contamination of groundwater supplies.

VII. Recommendations

Based on the conclusions presented in the previous section, the study raises several concerns which the Rhode Island Department of Environmental Management (RI DEM) needs to address with regard to the problem of managing sea level rise. This study has focused on determining the potential impacts for several scenarios of sea level increase ranging from 1-9 feet. Moreover, policy makers should understand the consequences of reliance on a particular model in light of the uncertainty associated with any particular projection model. In terms of making policy decisions, RI DEM will ultimately have to decide the appropriate projection to follow. This study recommends that in assessing impacts and evaluating planning solutions, policy makers should focus on the 1-3 foot range of sea level rise and with greater emphasis on the lower level, i.e. 1 foot. The 1 foot increment is the closest whole foot approximation to the historic rate. It is also important to understand the potential long term implications for the more severe sea level rise predictions and to closely monitor and adjust strategies to address these more serious impacts.

Reliance on a predictive model more consistent with historic trends is also more practical and defendable because there is data to support the trend. Nevertheless, planning and regulatory agencies should be alert to any changes in sea level rise projections and be aware of the potential for significant impacts. It is recommended that agencies such as the RI DEM consider the following issues when evaluating sea level rise management strategies:

1) When determining policy for land use development, first consider those areas which are already prone to flooding and where there is a high density of structures that could be potentially affected.

2) RI DEM should use a cost-benefit approach when evaluating alternatives, such as whether to build, or relocate in the event of a significant storm with sea level rise. During this evaluation, one should also realize that the magnitude of change from sea level rise is dependent on particular circumstances and requires careful consideration of many interrelated factors.

3) RI DEM should also study in more detail the other physical effects such as coastal erosion, groundwater contamination, and wetlands degradation. An appropriate policy action should consider other physical effects such as coastal erosion and groundwater impacts as well as potential loss of wetlands. In the short term, since wave runup is not as critical a factor, coastal erosion may not play as great a role, however over the long term, continual wave action and inundation may cause additional coastal erosion.

4) RI DEM should perform a more detailed analysis of the groundwater effects that may occur due to sea level rise and saltwater intrusion.

5) RI DEM, or other responsible agencies should continue to reevaluate different predictive models and monitor trends in sea level rise. Continued monitoring of sea level rise and awareness of current projections by the scientific community is necessary to evaluate and adjust strategies.

6) Because sea level rise has many resultant effects, it is critical that policy makers make informed decisions. In all cases, there are complex decisions to be made by individuals or organizations responsible for the management of both financial resources and natural resources. Therefore, it is critical that local community officials and planners as well as state regulators and legislators be aware of the effects of sea level rise and have at least a cursory understanding of the coastal processes involved and the potential economic consequences.

7) Policy makers within RI DEM should utilize the tools of regulatory, or legislative action to formulate strategies for reducing or mitigating the effects of sea level rise in a community or state. Their approach may include: requiring permits for coastal development; regulation through local zoning ordinances; purchasing of private land, etc. In the interim, RI DEM should continue to monitor sea level rise and the public should be informed of potential future impacts.

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APPENDIX A
HYDRAULIC ANALYSIS

IV. Hydraulic Analysis

a. General. Two types of wave processes govern hydraulic analysis of coastal flooding for this investigation. First, a wave height analysis was performed to determine wave heights and corresponding wave crest elevations for areas inundated by tidal flooding. Secondly, a wave runup analysis was performed to determine the height and extent of runup beyond the limit of tidal inundation. Results of these analyses were combined into a wave envelope, which was constructed by extending the maximum wave runup elevation seaward to its intersection with the wave crest profile. Methodology is described in detail in "Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping," Third Draft, Federal Emergency Management Agency (FEMA), July 1989.

Wave height methodology is based on procedures originally developed by the National Academy of Sciences (NAS), and described in their 1977 report entitled: "Methodology for Calculating Wave Action Effects Associated with Storm Surges." Three major concepts form the basis of the NAS methodology. First, a storm surge on the open coast is accompanied by waves, with the maximum height of these waves, at any point, directly related to water depth. Secondly, natural and man-made obstructions will dissipate energy; thereby, diminishing breaking wave height. Thirdly, throughout unimpeded reaches between obstructions, new wave generation can result from wind action which adds energy; increased wave height being related to distance and mean depth over the unimpeded reach. Wave height analysis was conducted using FEMA computer program "Wave Height Computations for Flood Insurance Studies," Version 3.0, September 1988.

Stone and Webster Engineering Corporation developed procedures for wave runup analysis in their "Manual for Wave Runup Analysis, Coastal Flood Insurance Studies," November 1981. It is essentially a composite slope runup procedure, relying heavily on data developed by the Corps of Engineers for presentation in the "Shore Protection Manual." The FEMA computer program "Wave Runup," Version 2.0 was employed for this study.

An erosion assessment is also performed at each location investigated prior to initiating wave height and runup procedures, previously referenced, above when coastal sand dunes may have a significant effect on flood levels. At Barrington, there are no significant sand dunes at the sites investigated; therefore, an erosion analysis was not conducted.

b. <u>Methodology</u>. The first step in conducting the hydraulic analysis for this study was to perform a thorough review of relevant wave analysis developed for the draft "Flood Insurance Study (FIS), Barrington, Rhode Island," dated January 1993, and completed by ENSR Consulting and Engineering. A field investigation was conducted along the entire Barrington shoreline to become familiar with physical features impacting the flood hazard analysis. A vicinity map of Barrington and a transect location map are shown on figures 1 and 2, respectively.

The purpose of this study is not to revise the recent draft Barrington FIS. Rather, the intent is to evaluate effects of future sea level rise on existing flood hazard zones. The ENSR analysis was recently completed, implementing the latest FEMA procedures; therefore, we determined that it would be an adequate reference data base.

The base flood or 100-year stillwater level used for existing conditions was presented in the draft Barrington FIS. This level is in close agreement with recent studies conducted by the Corps of Engineers and presented in "Tidal Flood Profiles - New England Coastline," September 1988. For the Barrington and Palmer Rivers, ENSR conducted a storm surge routing analysis to account for stage reductions, due to confined channel and bridge geometries. These levels were adopted for this study. Levels used for existing and sea level rise scenarios are shown in table 1. Sea level rise conditions were developed in even foot increments to simplify the hydraulic analysis. This assumption is consistent with the relative uncertainty in predicting future sea level, with the goal being to cover the range of predictions made by the research community. In all cases, sea level rise was just added to ENSR base flood levels.

BARRINGTON, R.I.

LOCATION VICINITY MAP

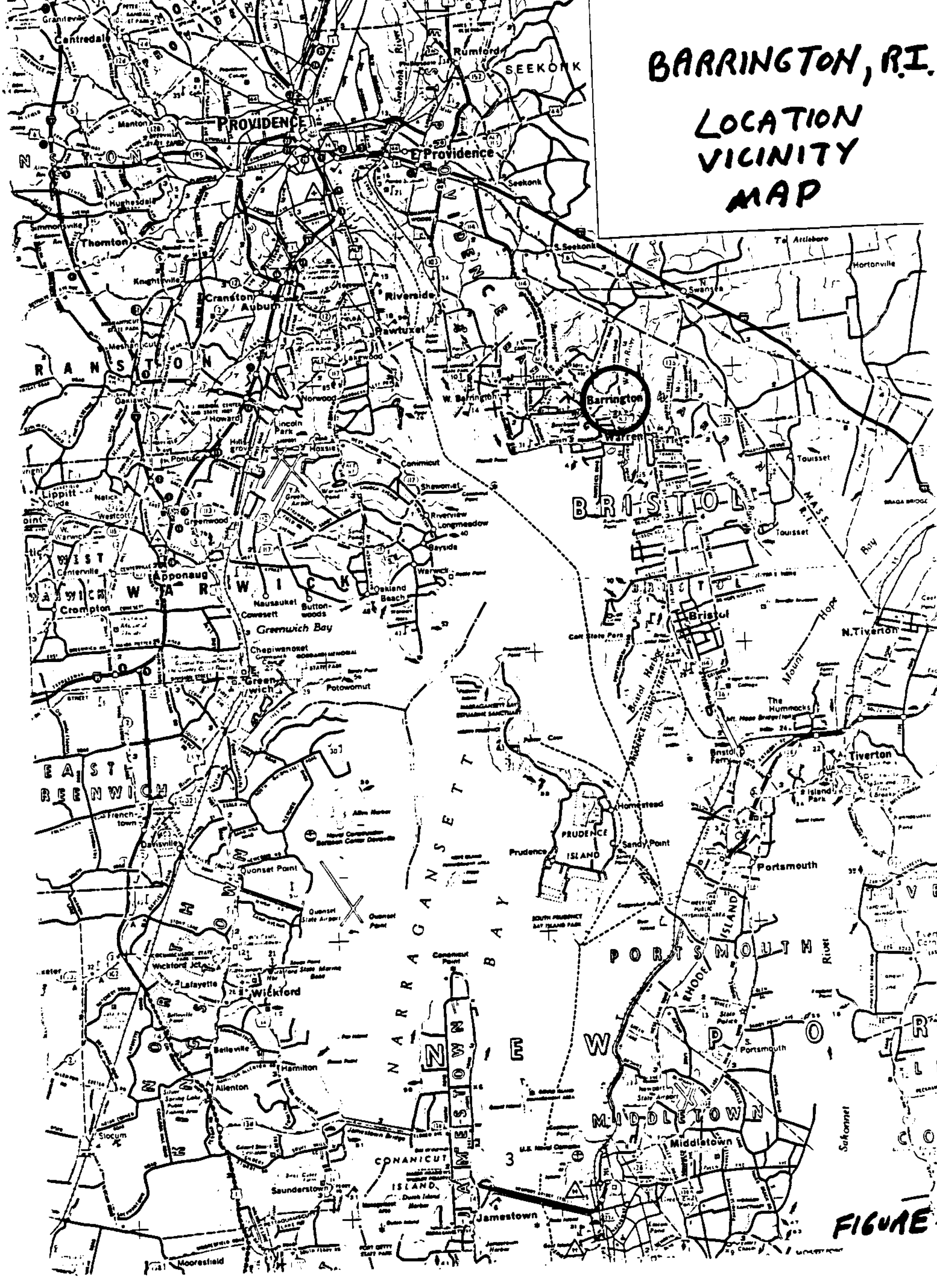


FIGURE 1

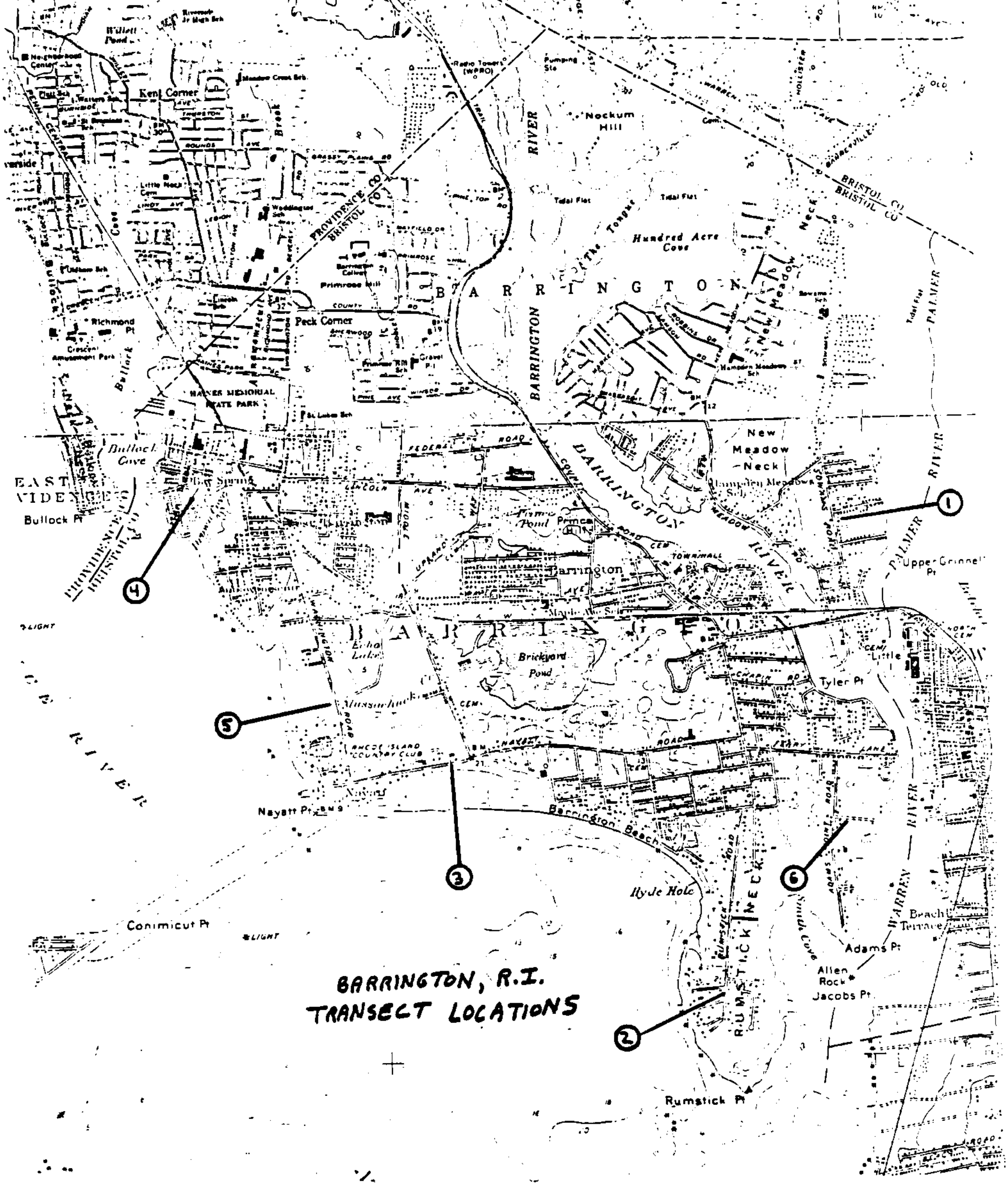

BARRINGTON, R.I.
TRANSECT LOCATIONS
1
2
3
4
5
6
BARRINGTON
Barrington
BARRINGTON RIVER
PALMER RIVER
WARREN RIVER
PROVIDENCE CO
BRISTOL CO
Nockum Hill
Hundred Acre Cove
Tidal Flat
The Tongue
New Meadow Neck
Kent Corner
Peck Corner
Primrose Hill
Barrington College
Richmond Pt
Crescent Amusement Park
Bullock Cove
Bullock Pt
HAINES MEMORIAL STATE PARK
Brickyard Pond
Echo Lake
Prince Hill
Upper Grinnell Pt
Tyler Pt
RHODE ISLAND COUNTRY CLUB
Nayatt Pt
Barrington Beach
Hyde Hole
RUMSTICK NECK
Rumstick Pt
Adams Pt
Allen Rock
Jacobs Pt
Beach Terrace
Conimicut Pt
Radio Towers (WPRO)
Pumping Sta
Hampden Meadows Sch

FIGURE 2

TABLE 1

BARRINGTON SEA LEVEL RISE INVESTIGATION
BASE FLOOD LEVELS

Sea Level Rise Condition (ft)	100-Year Stillwater Level (ft, NGVD)		
	Transect 1	Transect 6	Transects 2-5
0-ORIG*	9.1	13.8	14.8
1	10.1	14.8	15.8
2	11.1	15.8	16.8
3	12.1	16.8	17.8
6	15.1	19.8	20.8
9	18.1	22.8	23.8

*Refers to original 1993 ENSR FIS analysis

In order to conduct the analysis of wave height and wave runup for future sea level rise scenarios, some adjustments to the original ENSR transect geometries were necessary. Changes were made, using available mapping, field observations, and best engineering judgement. Some transects were extended to accommodate the increased future sea level rise conditions. For continuity, the offshore wave data, determined by ENSR, was carried throughout this study. All input and output files from the computer analysis are contained in a magnetic disk in Appendix A.

c. Results. In brief, with future sea level rise, larger and greater waves will be able to progress further landward due to increased water depths. The net result will be a significant increase in wave crest profile and runup elevations. Increased wave energy will contribute toward added propensity for storm damage in the coastal zone. Table 2 summarizes hydraulic analysis for each transect. For all transects the elevation range for both A and V zones is shown for each sea level rise condition evaluated. Also displayed is the shoreward migration of the initial "A/V" zone interface. "V" zones contain wave heights or runup at or exceeding three feet, while "A" zones include waves less than three feet. Substantial shoreward migration of the

Table 2 - SENSITIVITY OF V AND A ZONE TO SEA LEVEL RISE

TRANSECT 1

SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	11	11-9	0
1	13-12	12-10	33
2	14-13	13-11	71
3	15-14	14-12	188
6	18-17	17-15	203
9	21-20	20-18	340

TRANSECT 2

SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	21-17	17-15	0
1	23-18	18-16	4
2	24-19	19-17	22
3	25-20	20-18	52
6	29-23	23-21	171
9	32-26	26-25	235

TRANSECT 3

SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	21-17	17-15	0
1	23-18	18-16	10
2	24-19	19-17	21
3	25-20	20-18	31
6	29-23	23-21	81
9	32-26	26-24	100

Table 2 - (continued)

TRANSECT 4

SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	20-17	17-15	0
1	21-18	18-16	2
2	22-19	19-17	4
3	23-20	20-18	55
6	26-23	23-21	1623
9	29-26	26-25	2035

TRANSECT 5

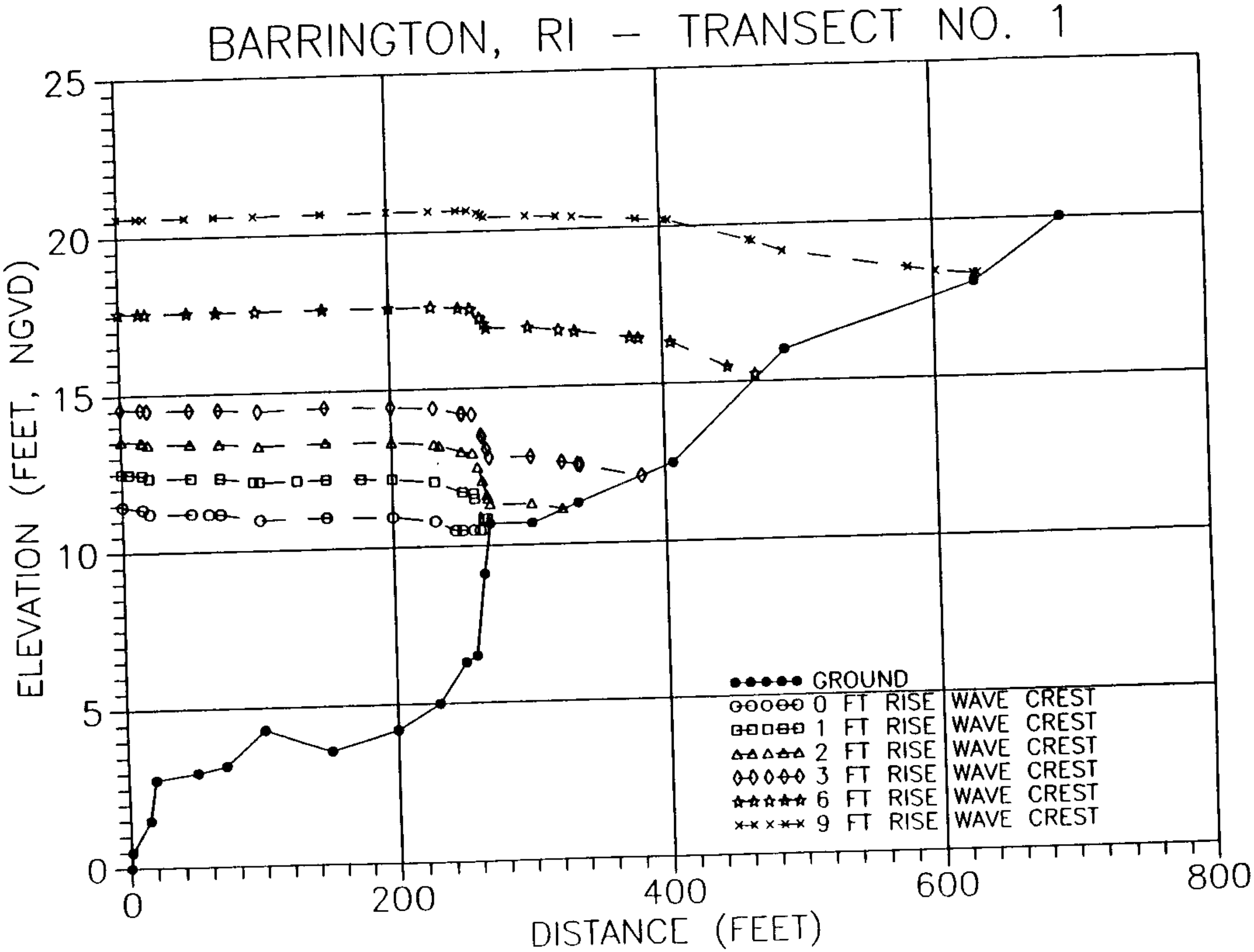
SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	20-17	17-15	0
1	21-18	18-16	8
2	22-19	19-17	135
3	23-20	20-18	185
6	26-23	23-21	1174
9	29-26	26	1192

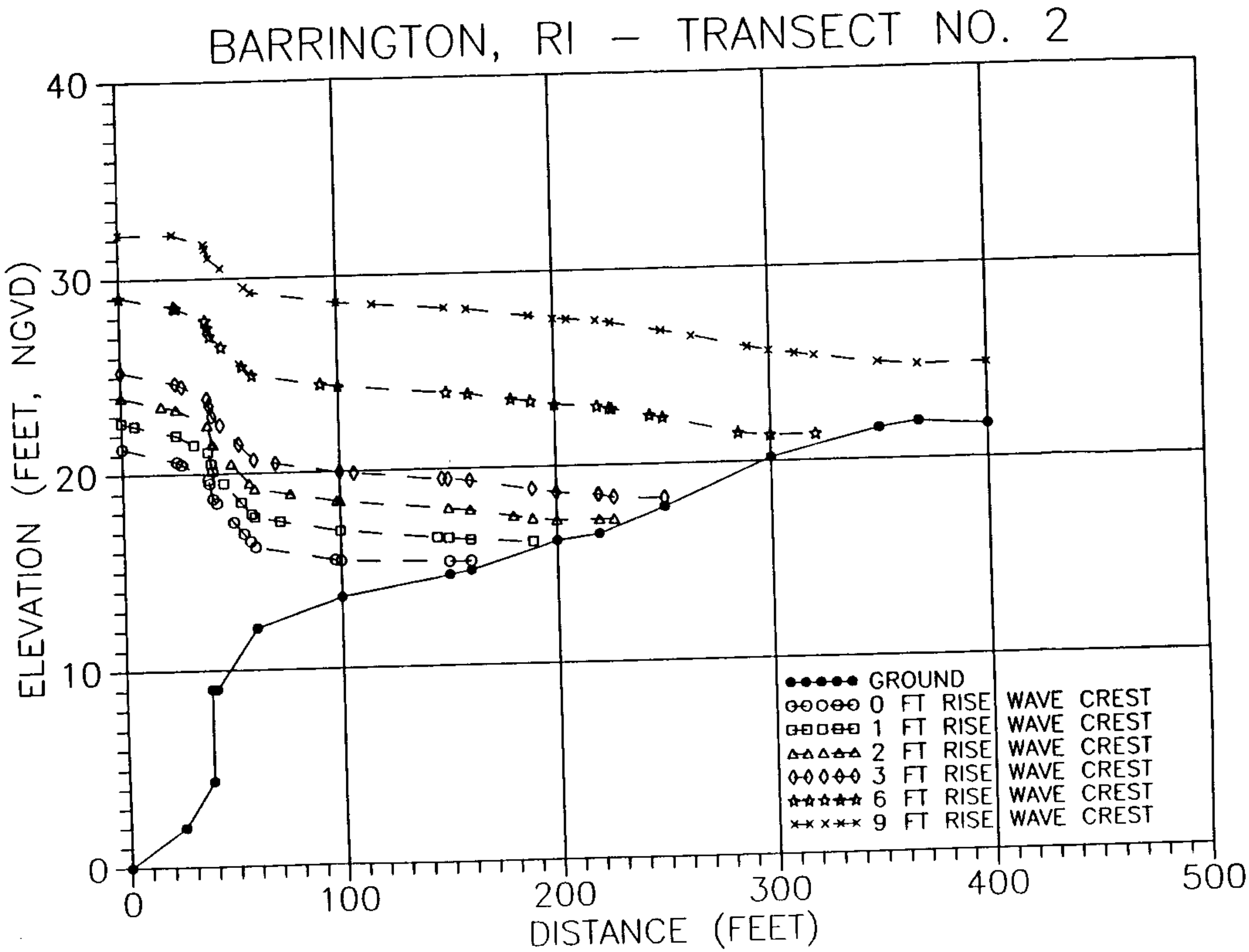
TRANSECT 6

SEA LEVEL RISE CONDITION (FT)	V ZONE ELEVATION RANGE (FT, NGVD)	A ZONE ELEVATION RANGE (FT, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (FT)
0-ORIG	20-16	16-14	0
1	21-17	17-15	7
2	23-18	18-16	15
3	24-19	19-17	22
6	28-22	22-20	52
9	31-25	25-24	184

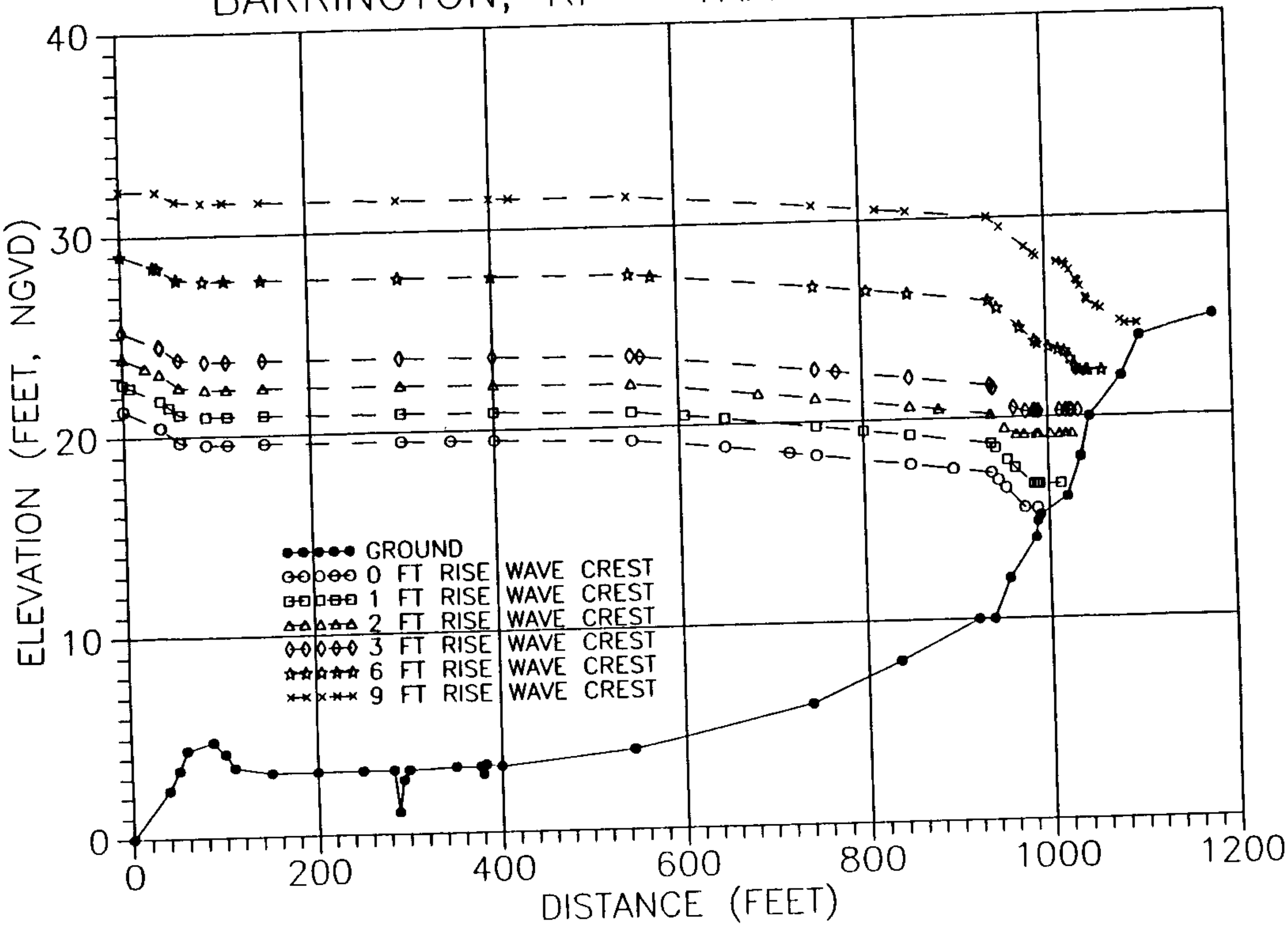
initial "A/V" zone interface occurs when the ocean stillwater, resulting from sea level rise, further inundates the land mass. The mapping of the sea level rise scenarios is discussed in the following section entitled: "Transect Interpretation and Mapping." The increased breaking wave forces will exert significant added damage pressure, especially in exposed areas along Narragansett Bay (transects 2 through 5). Plots of wave heights and runup for all transects for all cases analyzed are contained in Attachment A.

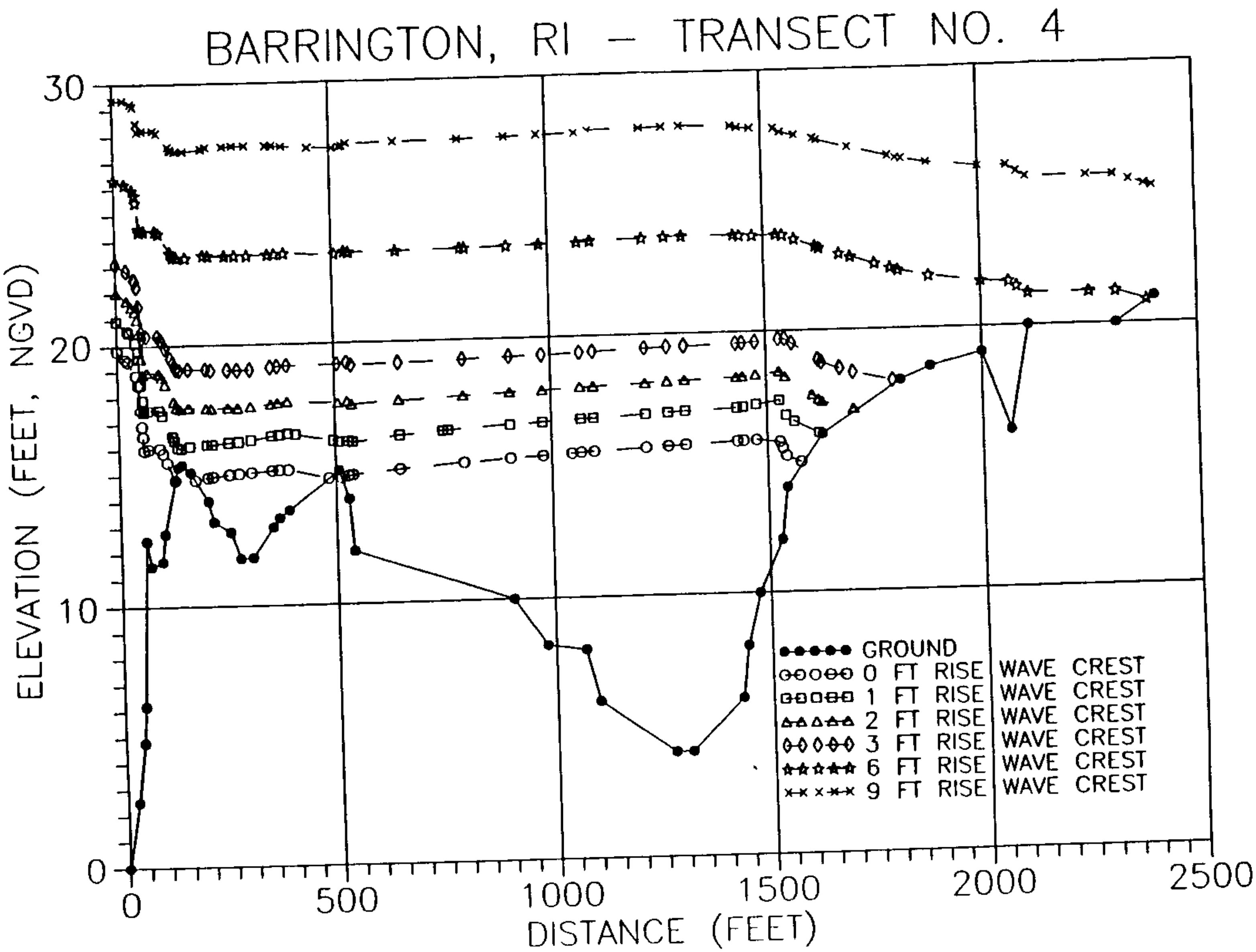
Attachment A
Transect Plots

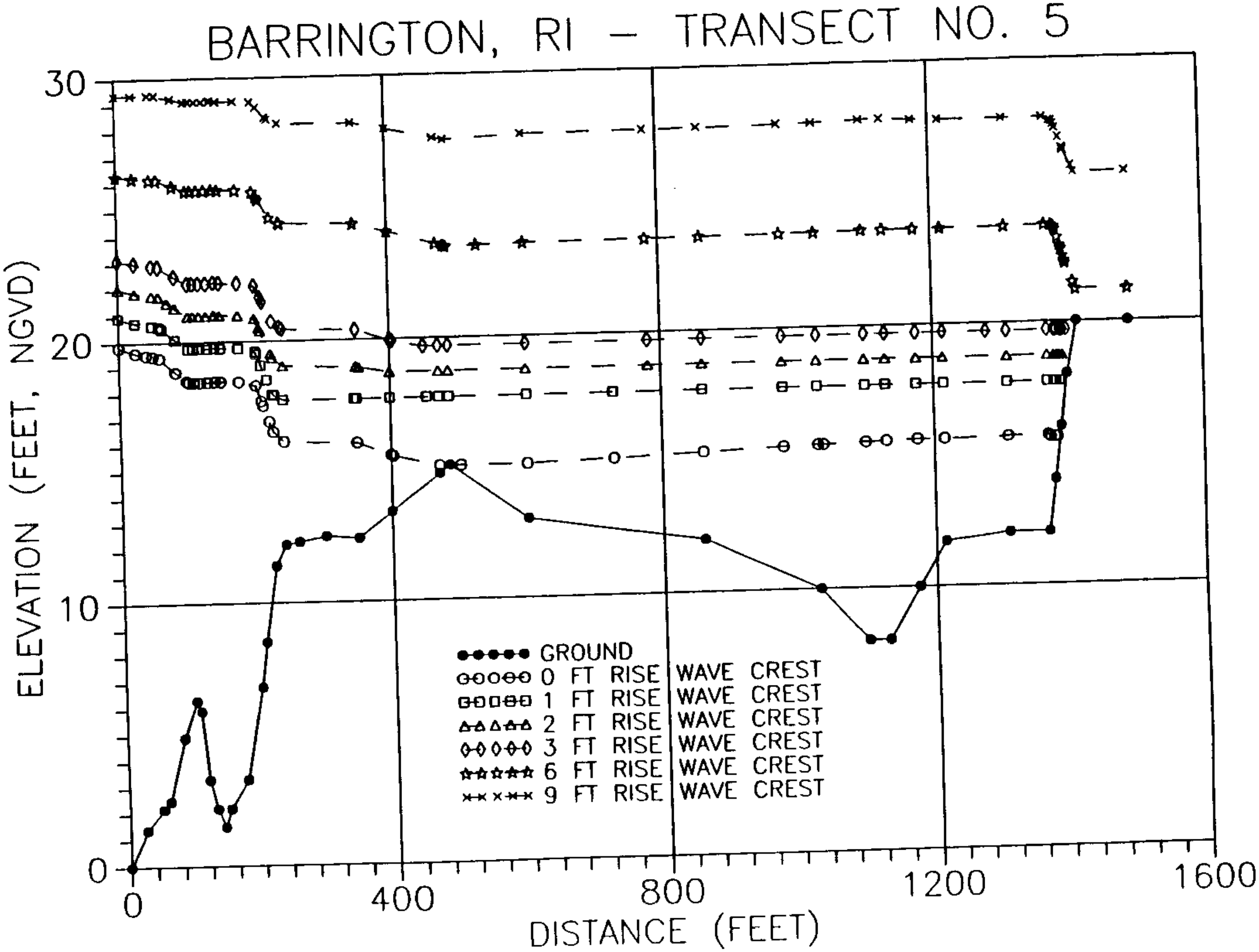

BARRINGTON, RI - TRANSECT NO. 1
ELEVATION (FEET, NGVD)
DISTANCE (FEET)
0
5
10
15
20
25
0
200
400
600
800
GROUND
0 FT RISE WAVE CREST
1 FT RISE WAVE CREST
2 FT RISE WAVE CREST
3 FT RISE WAVE CREST
6 FT RISE WAVE CREST
9 FT RISE WAVE CREST

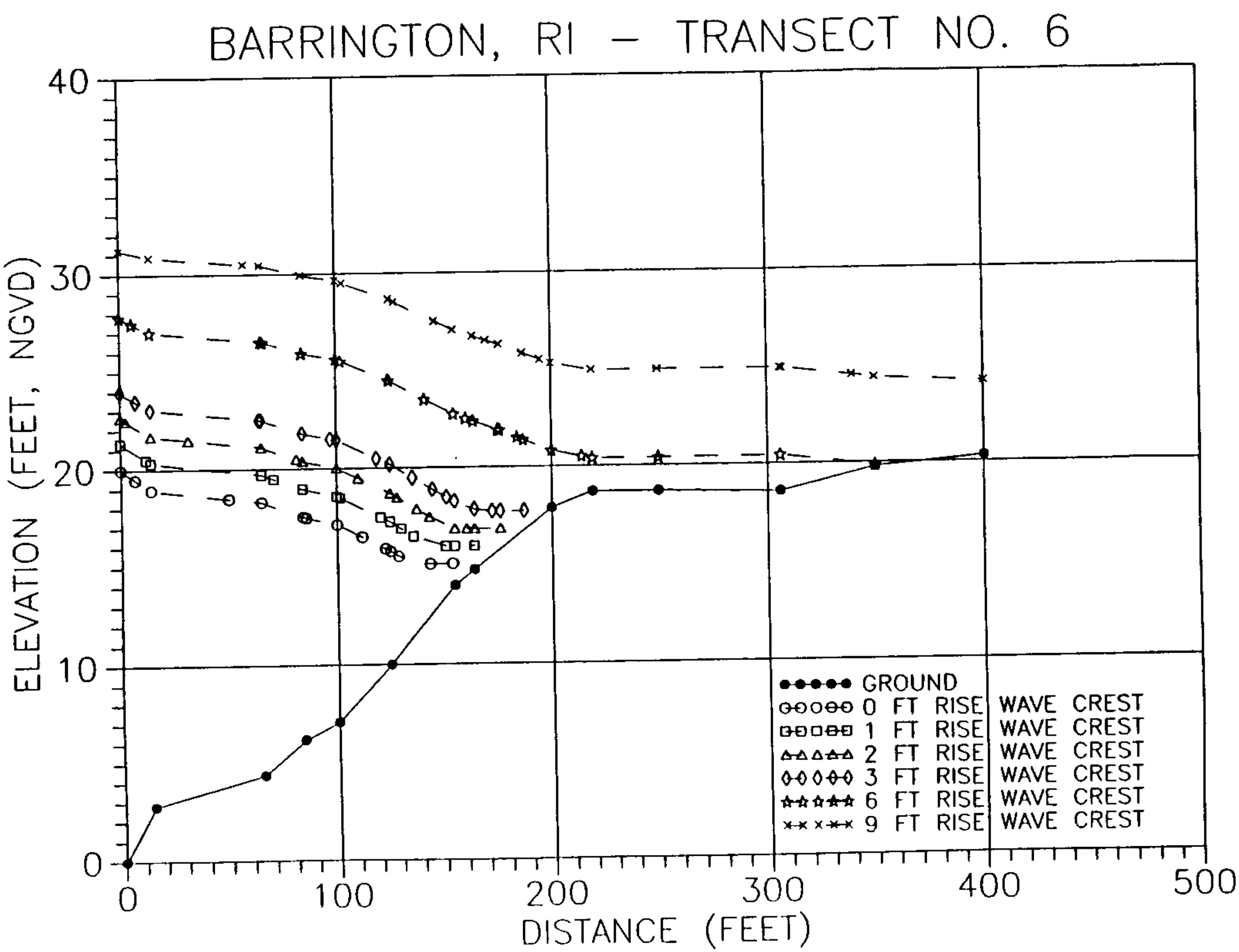

BARRINGTON, RI - TRANSECT NO. 2
ELEVATION (FEET, NGVD)
DISTANCE (FEET)
0
10
20
30
40
100
200
300
400
500
GROUND
0 FT RISE WAVE CREST
1 FT RISE WAVE CREST
2 FT RISE WAVE CREST
3 FT RISE WAVE CREST
6 FT RISE WAVE CREST
9 FT RISE WAVE CREST

BARRINGTON, RI – TRANSECT NO. 3




BARRINGTON, RI – TRANSECT NO. 4
ELEVATION (FEET, NGVD)
DISTANCE (FEET)
0
10
20
30
0
500
1000
1500
2000
2500
GROUND
0 FT RISE WAVE CREST
1 FT RISE WAVE CREST
2 FT RISE WAVE CREST
3 FT RISE WAVE CREST
6 FT RISE WAVE CREST
9 FT RISE WAVE CREST


BARRINGTON, RI - TRANSECT NO. 5
ELEVATION (FEET, NGVD)
DISTANCE (FEET)
0
10
20
30
0
400
800
1200
1600
GROUND
0 FT RISE WAVE CREST
1 FT RISE WAVE CREST
2 FT RISE WAVE CREST
3 FT RISE WAVE CREST
6 FT RISE WAVE CREST
9 FT RISE WAVE CREST


BARRINGTON, RI - TRANSECT NO. 6
ELEVATION (FEET, NGVD)
DISTANCE (FEET)
0
10
20
30
40
0
100
200
300
400
500
GROUND
0 FT RISE WAVE CREST
1 FT RISE WAVE CREST
2 FT RISE WAVE CREST
3 FT RISE WAVE CREST
6 FT RISE WAVE CREST
9 FT RISE WAVE CREST